Fishery Data Series No. 10-85

Movements and Spawning Locations of Lake Trout in the Tangle Lakes System

by

Brendan Scanlon

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA SERIES NO. 10-85

MOVEMENTS AND SPAWNING LOCATIONS OF LAKE TROUT IN THE TANGLE LAKES SYSTEM

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ABSTRACT

During August 2004, 40 lake trout *Salvelinus namaycush* were captured in the connected Tangle Lakes (Upper, Round, Shallow, and Lower) in Interior Alaska. These fish were implanted with radio transmitters and tracked for two years in an attempt to locate all of the significant spawning locations within the lake complex. Describing potential movements among the lakes as well as between spawning areas were of primary interest. The purpose of this study was to collect data that would help design a future study to estimate annual yield potential of lake trout in the sport fishery. Sampling and tracking results showed a moderate degree of movement between the lakes. Most movements occurred between Shallow and Round Tangle lakes whereas almost no movement of fish in or out of Lower Tangle Lake occurred. Only one spawning site was located, which was the same site that was previously-identified on Round Tangle Lake. Despite using radiotelemetry, visual surveys, and scuba divers, no spawning sites were located in the other three lakes. However, lake trout may spawn in the inlet stream of Lower Tangle Lake. This supposition can be attributed to the inlet stream containing suitable spawning habitat and the fact that some radio-tagged fish were located there during fall. Telemetry data was inconclusive in determining if the lake trout in the four connected lakes represent a single population. The results of this study suggest more work is required to locate additional spawning sites so a yield potential model can be used to set a sustainable sport harvest, and recommendations for future research are discussed.

Key words: Lake trout, *Salvelinus namaycush*, radiotelemetry, spawning, yield potential, Tangle Lakes, Alaska.

INTRODUCTION

In the Tanana River drainage, the most popular fishery for lake trout *Salvelinus namaycush* occurs in the Tangle Lakes system. The Tangle Lakes system is composed of four closely-connected lakes (Upper, Round, Shallow, and Lower Tangle lakes) that are intersected by the Denali Highway, 21 miles west of the town of Paxson (Figure 1). These lakes vary in surface area from 140 to 200 ha and in maximum depth from 20 to 30 m. These lakes flow into the Delta River, which eventually flows into the Tanana River. Two other nearby lakes, Glacier and Landmark Gap, drain into the Tangle Lakes through separate small streams. Glacier Lake drains via an approximate 16-km section of Rock Creek and Landmark Gap Lake drains via a small unnamed creek which is approximately 10 km in length. Another lake, Landlocked Tangle Lake, is close to Upper Tangle Lake but is not connected to the system.

All seven lakes contain lake trout. Camping and fishing are popular in this area. Two campgrounds and two lodges are nearby, and two boat launches (one each on Upper Tangle and Round Tangle lakes) provide easy access. In addition to lake trout, other species found in the Tangle Lakes include burbot *Lota lota*, Arctic grayling *Thymallus arcticus*, round whitefish *Prosopium cylindraceum*, humpback whitefish *Coregonus clupeaformis*, and longnose sucker *Catostomus catostomus*.

Due to concerns of overexploitation, the harvest limit for lake trout in Tangle Lakes was reduced in 1987 from 12 fish per day (only two of which could ≥20 inches or 508 mm FL), to just one fish per day, which must be ≥18 inches or 457 mm TL. This resulted in a considerable drop in annual harvest. Harvests of lake trout from the Tangle Lakes averaged 989 fish/year (SD = 742) during the period 1978–1986 (Mills 1979-1987). Since the regulation change, annual harvests have dropped considerably, to an average of 343 fish/year (SD = 138) during the period 1988–2007 (Mills et al. 1989–1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. (2004, 2006a, b, 2007, 2009a,b, 2010; Table 1). Annual estimates of catch are only available since 1990 (after the regulation change). From 1990 to 2007, catches have ranged from 523 to 3,132 fish and have averaged 1,721 (SD = 755; Mills et al. 1991–1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2009a,b; Walker et al. 2003 (Table 1).

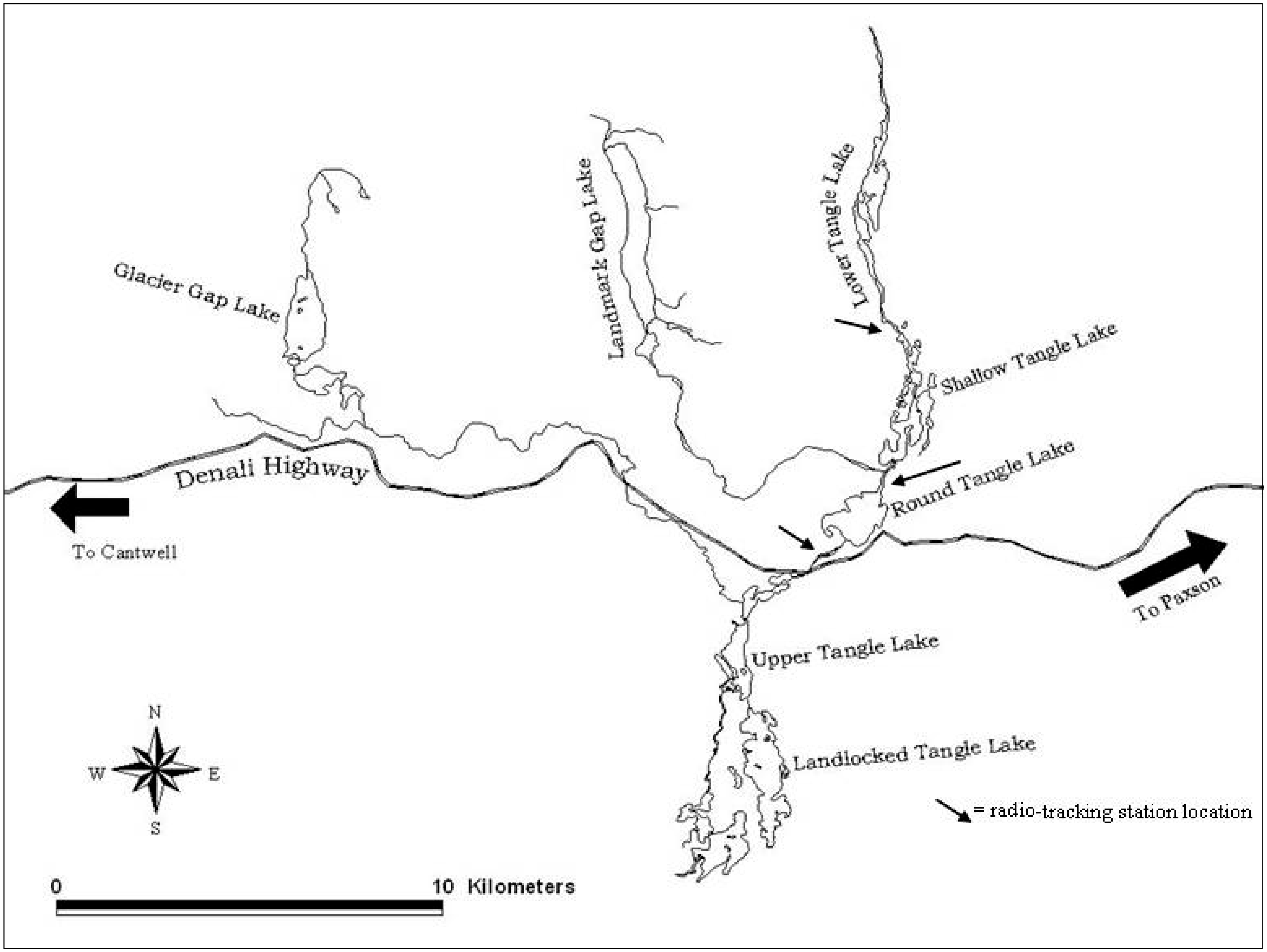

Figure 1.–The Tangle Lakes system (location of radio-tracking stations denoted).

Table 1.–Estimated number of angler days, lake trout harvested, lake trout caught, lake trout caught per angler day, and lake trout harvested per catch in Alaska, 1990–2007, and harvest and catch of lake trout in Tangle Lakes, 1990–2007.

		Number of Lake Trout Caught/Angler				*Tangle Lakes*	
Year	*Angler Days*	*Harvested*	*Caught*	*Day*	*Harvested/Caught*	*Harvest*	*Caught*
1990	1,589,087	12,602	42,443	0.04	0.20	236	523
1991	1,607,317	13,772	35,670	0.03	0.41	472	988
1992	1,651,296	12,525	43,295	0.05	0.26	208	1,488
1993	1,669,388	13,094	53,578	0.04	0.27	597	2,668
1994	1,695,551	11,374	45,107	0.03	0.26	416	1,342
1995	1,738,924	8,412	28,262	0.02	0.25	246	928
1996	1,262,580	9,772	34,781	0.07	0.21	235	2,519
1997	1,263,675	7,486	30,701	0.07	0.20	240	3,132
1998	1,153,277	5,985	22,807	0.06	0.20	290	1,222
1999	1,574,744	9,948	45,910	0.07	0.19	484	2,034
2000	1,649,833	6,292	32,176	0.06	0.21	367	1,534
2001	1,373,018	4,995	26,040	0.02	0.20	112	591
2002	1,404,084	7,178	43,380	0.03	0.17	338	2,221
2003	1,351,490	7,084	37,434	0.03	0.19	516	2,037
2004	1,466,586	7,934	44,051	0.03	0.18	270	976
2005	1,409,627	7,312	40,714	0.03	0.18	224	2,327
2006	1,357,415	3,103	29,239	0.02	0.11	292	1,076
2007	1,491,544	3,711	20,082	0.01	0.18	482	1,890
				Averages			
	1,483,858	8,477	36,426	0.04	0.21	335	1,639

Stock assessments of lake trout are difficult and costly because lake trout inhabit deep water and typically occur in low densities, particularly in large or remote lakes, and may result in biased or imprecise estimates. In the absence of stock assessments to determine sustained yields, the lake area (LA) model developed by Evans et al. (1991) is applied to lakes within Region III (which includes the Upper Copper River and Upper Susitna River area and the Arctic-Yukon-Kuskokwim Region (including the North Slope, Northwestern, Yukon River, Tanana River, Kuskokwim-Goodnews regulatory areas). This model uses surface area to predict annual surplus production or annual yield potential (YP) in units of biomass (lbs/ha/yr). Biomass is then divided by mean weight of a harvested lake trout, which must be representative of the population, to calculate the annual number of lake trout that can be harvested.

In Region III, a surrogate for the mean weight of harvested lake trout is typically estimated by sampling lake trout on the known spawning areas using beach seines because large sample sizes can be efficiently attained (Scanlon 2004). If annual harvests consistently exceed the LA model estimate of yield potential, either a conservative management action may be taken to reduce harvest, or a more rigorous stock assessment may be initiated to determine if the LA model estimate of yield potential is appropriate.

Collecting weight information using beach seines is a preferred method over gillnetting. Unacceptable mortality rates using gill nets as high as 39% have been observed in Landlocked Tangle Lake (Burr 1988) and 40% in Upper Tangle Lake (Burr 1989), which was largely due to the duration nets were soaked (e.g., up to 3 hours in some instances as opposed to 20-30 minutes, which is typical). The approach of sampling spawning fish for the LA model assumes that the mean weight of the fish collected from the spawning aggregations is similar to the mean weight of lake trout harvested by anglers in that year. This approach is considered reasonable for these lakes because, given the paucity of large lake trout and the one fish bag limit, it is not likely that people interested in harvesting fish will release a fish $\geq$18 inches, the lower length limit. In addition, weight and length data collected when sampling spawning lake trout may also be used to estimate mean weight for a variety of length intervals to assess the impact of possible angler selectivity. While estimating average weight of the harvest directly (e.g., from an onsite creel survey) would not be subject to this source of bias, it would likely be very expensive and difficult to obtain a representative sample given the nature of the fishery. It is recognized that fecund fish (especially females) would likely weigh more than the same fish at other times of the year, thus leading to a more conservative (lower) estimate of YP in fish/ha/year (Scanlon 2004).

Although studies have been conducted to estimate abundance of lake trout in Upper Tangle Lake and nearby Glacier Lake (Burr 1987, 1988 and 1992), the information obtained was insufficient for estimating mean weight of lake trout greater than the 18-in length restriction. In 1986, Burr (1987) estimated an abundance of 2,686 lake trout $\geq$250 mm FL (SE = 621) in nearby Glacier Lake using a two-event mark-recapture experiment and while sampling in September, a spawning aggregation was identified. In 1989, Burr (1990) again conducted a stock assessment of lake trout in Glacier Lake, estimating an abundance of 3,142 lake trout $\geq$275 mm FL (SE = 669). In 1988, Burr (1989) estimated an abundance of 211 lake trout $\geq$250 mm FL (SE = 33) in Upper Tangle Lake. In an attempt to identify spawning locations in 1991, Burr (1992) sampled only 22 fish in Round Tangle Lake and 18 in Shallow Tangle Lake.

This study was undertaken to collect data that would help design a future study to estimate annual yield potential of lake trout in the sport fishery using the LA model. Five issues needed to be addressed to successfully apply the LA Model to Tangle Lakes: 1) the lack of information on locations of spawning areas and movements between spawning areas that precludes an unbiased and precise estimate of mean weight; 2) whether beach seines can effectively capture lake trout at their spawning locations; 3) the extent to which fish migrate between lakes in the Tangle Lakes complex and Glacier and Landmark Gap lakes; 4) whether to apply the LA model to the Tangle Lake complex as four individual lakes, or treating the complex as a single lake; and, 5) the adequacy of current harvest reporting for evaluating if YP is being exceeded.

Relative to the issues of locating and sampling spawning areas, in 1991, Burr (1992) found visual surveys to be ineffective in finding aggregations of spawning lake trout in Round Tangle and Lower Tangle lakes and suggested that the majority of lake trout in these two lakes spawn in water too deep to identify visually. Only one aggregation was visually located in Round Tangle Lake and none were found in Lower Tangle Lake. Most spawning fish in this study were found using small mesh gill nets set over potential spawning sites, as determined by the presence of preferred substrate size and water depth for spawning lake trout. Moreover, the relative timing of when the fish in Tangle Lakes spawn was also in question. In most Alaskan lakes spawning is generally centered on September 15 as water temperatures approach 6.0° C (J. Burr, Fisheries Biologist, ADF&G, Fairbanks; personal communication). In contrast Burr (1992) captured several lake trout and could not expel gametes from captured fish until 14 September and lake trout were not observed to be actively spawning until 1 October when the water temperature was 2.8° C. However, because of the limited nature of this spawning information, there was no reason to suspect that the initiation of spawning is different in Tangle Lakes than in other Interior Alaskan lakes (J. Burr, Fisheries Biologist, ADF&G, Fairbanks; personal communication).

The issue of movement between the Tangle Lakes complex and Glacier or Landmark Gap lakes arose because Burr (1989) captured a lake trout in Glacier Lake that had been tagged in Upper Tangle Lake during the stock assessment work conducted during the late 1980s and early 1990s. The movement of this fish indicated that flows in Rock Creek are periodically sufficient to serve as a migration corridor between Glacier and Tangle Lakes, but the degree of exchange between these lakes was uncertain. However, based on observations by Burr (1987), the flows in Rock Creek were very low during midsummer and appeared to prohibit any fish passage. Because of the distance between the lakes and the observed low flows, it is unlikely that any meaningful exchange occurs between the two lakes. The likelihood of exchange between Landmark Gap and Tangle Lakes appears far less because the stream connecting them is small, intermittent, with high gradient (approximately 400 ft over 10 miles).

In the Tangle Lakes complex, application of the LA model is confounded by the physical nature of the system. Generally the LA model is applied to a single lake basin, but in the Tangle Lakes, where the lakes are connected by short reaches of flowing water (e.g., 100 – 300 m) where fish passage is possible, it is unclear whether the best application of the model is to calculate yield for each lake individually, or to combine the surface area of the four connected lakes and calculate one estimate of yield potential. These two approaches result in different estimates. Calculating YP using the combined area of all four lake (820 ha) results in an estimate of 502 kg/yr (0.61 kg/ha/yr). Calculating the YP using the surface area of each individual lake and summing the estimates results in a YP of 739 kg/yr (0.9 kg/ha/yr). Understanding the degree of mixing of lake trout between lakes was needed to help correctly apply the LA model and ensure that the Tangle Lakes are managed to keep annual harvests near or below the YP.

The primary goal of this experiment was to collect data sufficient to design a future study to sample lake trout for use in the LA model using radiotelemetry. The data collected would also help in determining if harvest data are currently reported in sufficient detail (e.g. by each lake) for use in applying the LA model and in designing a mark-recapture experiment if needed. Burr (1991) successfully used radiotelemetry to locate the spawning location for lake trout in Fielding Lake that enabled researchers to conduct multi-year experiments to estimate abundance and length composition. Documenting the movements of radio-tagged lake trout is essential for designing a plan to sample lake trout on spawning areas. For example, it can help to determine if a representative sample of weights can be attained by sampling a subset of the spawning areas, if some shoals are ill-suited (i.e., too deep) for seining. Documenting movements will also aid in defining stocks among the lakes in the Tangle Lakes complex and between the Tangle Lakes and other nearby lakes (i.e., Glacier Lake, and Landmark Gap Lake) and shed light on whether lake specific harvest data are needed to effectively manage the system.

Movement and catchability information is necessary for planning an experiment to estimate population parameters (e.g., abundance, length composition, and annual mortality), which may eventually become a research goal. In Alaskan lakes where there can be several spawning locations for lake trout within a lake, it has been demonstrated that individual lake trout can be captured on several different spawning areas, within and between years (Scanlon 2004). Also, no evidence of skip-spawning has been found in studies at other nearby lakes (Wuttig 2010; Parker et al. 2001; Parker and Wuttig 2000). If the results of this experiment showed similar behavior in the Tangle Lakes system and if sufficient numbers can be captured, then it may be feasible to conduct future multi-year mark-recapture experiments to estimate abundance, length composition, and annual mortality.

OBJECTIVES

The objectives of this project were to:

1. identify spawning areas that accounted for 80% of the spawning population of lake trout within the four connected Tangle Lakes (Upper, Round, Shallow, and Lower) with 90% confidence using radiotelemetry;

2. for each spawning area identified, determine if seines can be used to capture lake trout or if gillnets are necessary; and,

3. describe locations and movements of lake trout $\geq$450 mm FL radio-tagged in the connected Tangle Lakes using radiotelemetry. Inter-lake movements and movement among spawning areas were of primary interest.

In addition, project tasks were to:

1. affix a uniquely-numbered Floy FD-94 anchor tag to each captured lake trout to collect movement and growth information if recaptured in subsequent years;

2. record length and sex information (when possible) from all sampled fish;

3. assess the feasibility of conducting a stock assessment should the need for size composition and abundance information be identified;

4. assess the need for more refined harvest data for comparisons with the most appropriate application of the LA model; and,

5. assess the need for additional work (e.g., deploying radio tags in Glacier and Landmark Gap lakes) to determine the interdependency of these lake and the Tangle Lakes complex.

METHODS

SAMPLING DESIGN

This study was designed to use radiotelemetry to monitor seasonal movements within and between connected lakes in the Tangle Lakes system and to locate all major spawning areas. Radio tags were to be distributed in a manner that would increase the likelihood that: 1) the most significant spawning areas among all four lakes will be located and, in the event of limited movement of lake trout among lakes; and, 2) the major spawning areas in each of the four lakes can be located. However, to account for the uncertainty in determining relative abundance and to ensure at least some fish are tagged in every lake, the project was designed to deploy no less than five and no more than 14 tags in any one lake. In an attempt to obtain a comparable measure of relative fish densities, crews tried to distribute a similar array (gill nets and jug lines) and equal amounts of fishing effort for each day fished in each lake.

Methods used for tracking of radio-tagged fish included aerial surveys from fixed-wing aircraft, tracking from boats, and three radio-tracking stations placed at strategic locations to record movement between lakes. Using this information, radio-tagged fish were located after dark by boat, when lake trout move onto spawning beds. When a radio-tagged lake trout was located in a potential spawning area (i.e., favorable water depth, substrate type), visual inspection of the site was made using high-powered, submersible lights and hand-held spot lights, and either gillnets or a beach seine was deployed to catch spawning lake trout. The decision as to which gear to use was based on substrate type (large boulders or small gravel) and water depth (seine is ineffective if water depth is $\geq$ 2.5 m). When a potential spawning location was identified without the presence of a radio-tagged fish, gear was deployed if a visual inspection revealed an aggregation of fish.

Radio-tracking stations were placed on stream shorelines between the lakes to detect movement between the lakes during the open-water season (Figure 1). Stations were erected in August 2004, immediately after the radio-tags were deployed and were in operation through October 2004, well after spawning had finished. They were activated again the following spring and operated through mid-October 2005. One aerial survey during winter was conducted to look for overwintering fish. An aerial survey was flown during early fall just prior to the fall sampling events in 2004 and 2005.

Based on previous work (Burr 1991) as well as the nature of the connecting streams, it was anticipated that movement between the Tangles lakes complex and Glacier Lake would be a rare occurrence, and movement between the Tangles lakes complex and Landmark Gap Lake would be extremely unlikely. Information needed to assess the degree of interchange between Tangle lakes and its neighboring lakes (Landmark Gap and Glacier lakes) and the potential for bias was collected by 1) conducting aerial tracking flights of these lakes to locate radio-tagged lake trout; and, 2) inspecting connecting creeks to assess the likelihood of fish passage (e.g., sufficient water depth and flow, low gradient, etc.).

FISH CAPTURE

In August 2004, lake trout were captured using variable mesh (0.75-in, 1.0-in, and 1.5-in bar or 1.9-cm, 2.5, and 3.8 cm) monofilament gillnets, baited jug lines, and hook-and-line gear. Gillnets were fished in areas most likely to be inhabited by lake trout. For example, nets were deployed perpendicular to the shoreline in deepwater trenches (≥10 m) and near drop-offs and stream inlets. Jug lines, which have been used successfully in other lake trout projects, were deployed throughout the lakes using a two-person crew. Between 24 and 48 jug lines were used at each lake depending on catch rates. These jug lines were constructed of a 45-cm section of PVC pipe encased in marine foam with a 10- to 25-m section of braided line hanging from the bottom of the float. A section of bait (whitefish caught as bycatch in the gillnets) just small enough for a lake trout to swallow was tied to the end with a noose knot, and the bottom of the line weighted with a one to three-ounce lead sinker. Captured lake trout were transferred to holding pens held until all sampling was completed in a particular lake. No fish were held longer than four hours.

The fall sampling event was conducted during the second two weeks of September. Sampling occurred during night because there are few fish on the spawning grounds during the day. Once a possible spawning location was identified, an evaluation of which gear type to use was made based upon water depth, substrate type, and distance from shore. If the water at a site was deeper than ~2.5 m (8 ft), contained large boulders, or was more than ~30 m (100 ft) from shore, then gill nets were used. If the water was 2.5 m or less, didn't appear to contain large boulders (which would hang up on the seine and allow fish to escape), and was 60 m or less from shore, then a seine (121 x 2.4 m or 400 x 8 ft) was deployed. Lake trout were sampled for length, sex, given a gray-colored Floy tag™ (numbers used: 1,025 – 1,231; 2,100 – 2,126; 43,325 – 43,370; 45,625 – 45,670; and 45,854 – 45,879) and released immediately after sampling. In addition, technicians searched for fish that had received a transmitter from the August sampling event.

Once a spawning location was identified, crews moved on to look for other sites rather than attempt to catch more fish because the main goal in September was to identify as many spawning locations as possible.

RADIO-TAG DEPLOYMENT AND TRACKING

In August 2004, a sample of 40 lake trout ≥450 mm FL was selected for radiotagging. Male adult lake trout have been shown to spend considerably longer amounts of time on spawning grounds (Martin and Olver 1980), and therefore an attempt was made to implant transmitters in only males, which could increase the number of spawning sites located during tracking events. However, lake trout show little sexual dimorphism; therefore, the sex of the sampled fish was unknown prior to implantation surgery. During surgery an attempt was made to determine sex by looking into the body cavity through the incision made for the transmitter and inspecting the gonads. Care was taken to minimize stress on all fish.

Lake trout receiving a transmitter were anesthetized in water and clove oil as described by Anderson et al. (1997). LOTEK (*MCFT-3A*) radio transmitters with unique codes spread over four frequencies and an expected life of 761 days were surgically implanted within the coelomic cavity of selected lake trout through a 2-3 cm incision along the linea alba, anterior to the pelvic girdle (Hart and Summerfelt 1975). Three to five sutures were used to close the incision. The outlet incision for the trailing antenna was posterior to the pelvic girdle. The procedure used for the placement of trailing antenna was similar to that described by Ross (1982). During the surgical procedure, fresh water was poured over the gills to prevent suffocation. All radio-tagged fish were retained until equilibrium was regained and then released 50 to 100 m away from capture sites.

The radio-tag deployment strategy was complicated because of the unknown distribution of lake trout and their major spawning areas, as well as, their unknown movement amongst the lakes. Under these circumstances, the sampling strategy sought to strike a balance between deploying in proportion to relative abundance (determined while deploying tags) and ensuring that some minimum number of tags was deployed in each lake. Rather than simply deploying 10 transmitters in each lake regardless of the distribution of effort or catches, lakes were sampled in an order based on a best guess of the lake's density of fish ≥450 mm FL, working from the smallest density to the largest: 1) Upper Tangle (smallest); 2) Shallow Tangle; 3) Lower Tangle; and, 4) Round Tangle (largest). This order was established to minimize the time required to deploy the tags.

Locations of radio-tagged fish were documented by aerial tracking surveys and radio-tracking stations. Aerial tracking surveys occurred before and after periods of expected lake trout movement. The surveys were conducted during prespawning (late-August, when the lake begins to cool down and before movement to spawning areas), and break-up (mid- to late-June, after open leads have been discovered and before lakes are ice-free). Locating fish consisted of flying over the Tangle Lakes study area in a systematic manner while listening for transmitter signals with a five-element Yagi antenna with 9 dBd gain mounted on a fixed-wing aircraft. Location of a radio-tagged lake trout was determined using a map and a GPS unit. If all radio-tagged fish were not located during an aerial survey in the Tangle Lakes, Glacier and Landmark Gap lakes were surveyed in attempt to find remaining fish.

Three radio-tracking stations were placed between the lakes to record the passage of radio-tagged lake trout between the connected Tangle Lakes (Figure 1). The radio-tracking stations were composed of integrated components: a power source (a 65 w photovoltaic solar panel connected to a 12-volt battery), a Lotek SRX-400 data collection computer and receiver, and two five-element Yagi antennas. The stations were to be in operation from late-May through late-October starting in August 2004 and finishing in October 2005.

CHANGES TO SAMPLING PROTOCOL IN 2005

In 2005, the fall sampling protocol was identical to that used in 2004 with the following exceptions: 1) the dates of sampling were changed to more completely coincide with spawning; 2) sampling efforts were focused on Round, Shallow, and Lower Tangle lakes only; 3) the number of tracking stations was reduced from three to two; and, 4) scuba divers were used to search for lake trout spawning locations as a means of searching for additional spawning areas.

Sampling commenced on 21 September to more closely coincide with peak spawning noted in 2004. Similar to 2004, radio-tagged fish were located via fixed-wing aircraft just before sampling to give crews daytime locations of tagged fish. That night, and for the next eight nights, one crew searched for spawning lake trout in Lower Tangle Lake and in the creek above the lake, while the other crew searched in Round and Shallow Tangle lakes. Both crews had access to boats equipped with jet units, enabling them to travel over and sample in shallow water safely. Searches were conducted via radio-tracking and by visual surveys with high-powered lights.

Based on preliminary 2004 results from the radiotelemetry data and visual observations, it appeared that there was limited mixing between Round, Shallow, and Lower Tangle lakes. Also, as demonstrated in the first year of this study and in previous studies (Burr 1992), it was very unlikely that spawning occurred in Upper Tangle Lake. Therefore, the most effort was concentrated in Round, Shallow, and Lower Tangle lakes with one crew dedicated to Lower Tangle Lake (including the likely spawning location in its inlet stream) for the duration of the sampling activities. As a cautionary measure, at least one night was spent in Upper Tangle Lake to confirm observations made in 2004 that there were no significant spawning aggregations present. In addition, because spawning was not likely in Upper Tangle Lake and no fish ever came close to the tracking station between Round and Upper Tangle, the tracking station between Upper and Round Tangle lakes was removed.

Potential spawning sites for lake trout in Lower Tangle Lake have been identified by Burr (1992) and during this experiment in September 2004 (Figure 2) using the identification criteria described in Appendix A1. Starting on 23 September and continuing for three days, two divers, certified through the Scientific Diving Program at the University of Alaska-Fairbanks, searched a subset of these areas for the presence of lake trout eggs lying on and within the substrate. Both of these divers had extensive research diving experience, and had received approved reciprocity agreements through UAF to conduct scientific diving for ADF&G. Upon reaching the potential spawning site, divers swam transects over the site from one to two meters apart from each other and parallel to the shore at depths from one to four meters. Divers searched on the bottom and were careful not to agitate the sediments to preserve visibility. Each diver was instructed on how to conduct the survey using underwater video footage provided by researchers in Ontario (Corbett 2003). One diver had an underwater digital camera to take pictures of eggs and substrate. Each diver dove for a total of approximately four hours (as was dictated by the number of air tanks that could be flown in) over a two day period during the study. At all times that divers were in the water, two to three ADF&G personnel were nearby observing from inflatable boats.

Because it required approximately 20 minutes to survey a likely spawning area and because approximately four hours of dive time were available, it was anticipated that only the most promising of the potential spawning areas would be surveyed. However, time allowed for other potential spots to be surveyed with priority given to locations where fish were either visually or telemetrically identified, and those with apparently the most suitable spawning substrates. Potential spawning areas were selected based on the locations of the radio tags during 2004 and 2005 and any confirmed visual observations. Based on 2004 results, it was concluded that the most likely, and perhaps the only unconfirmed spawning area, was a cluster of four sites located within the inlet stream (Figure 2). Therefore, divers surveyed this cluster over three days for a total of one hour of dive time.

If lake trout eggs were identified at a site, the location was marked with a GPS unit and with a reflective marker on the shoreline and sampled at night using the methods discussed earlier.

DATA COLLECTION

During both the August and September sampling events, all lake trout ≥300 mm FL were measured for fork length to the nearest millimeter, marked with individually numbered internal anchor tags, and given an event-specific secondary mark. In August 2004, all sampled lake trout received a left opercular hole-punch. During the September event, all sampled fish received an adipose clip as a secondary mark, and sex was determined by presence of sex products when possible. Locations and physical characteristics of the spawning sites (e.g., water depth, substrate type, etc.) were described. Location coordinates for these spawning sites were obtained using a Global Positioning System (GPS).

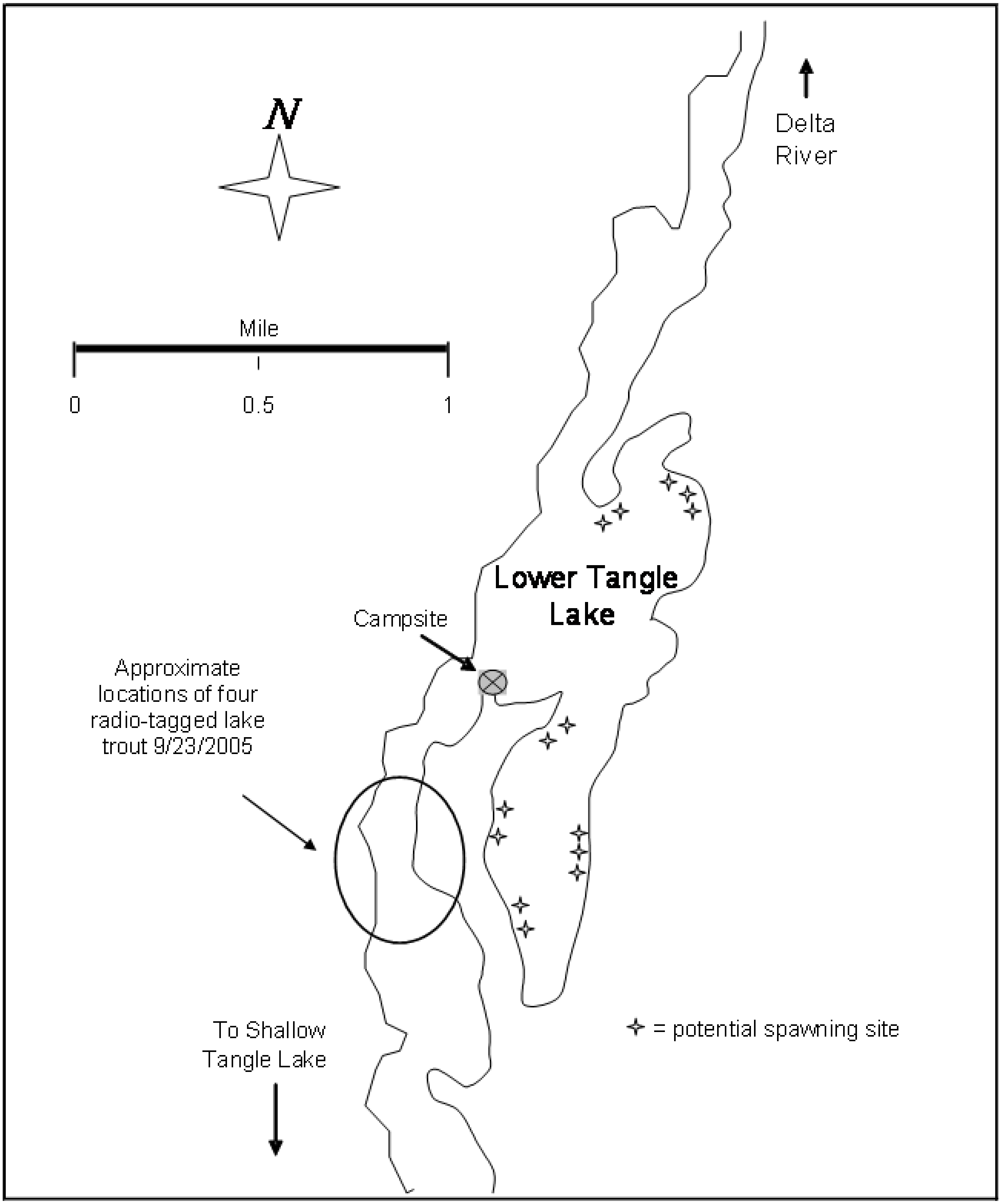

Figure 2.–Locations of potential spawning sites for lake trout based in and near Lower Tangle Lake on substrate and depth profiles.

During aerial tracking and boat surveys, coordinates of radio-tagged fish were stored using a GPS unit. Following surveys, dates and coordinates were entered into a Microsoft Excel spreadsheet. Data from radio-tracking stations were downloaded onto a laptop computer approximately every 30 days throughout the open water season and stations were removed for the year in late-October and reinstalled in May.

DATA ANALYSIS

Telemetry data and information from reported harvests of radio-tagged fish were combined in a table summarizing the fates of all radio-tagged lake trout. Aerial surveys, boat surveys, "ground-truthing" of radio tags, and harvest reports yielded discrete data that could be readily entered into a fate table, whereas continuous data obtained from the radio-tracking stations for fish that passed the stations is described in time-series graphs. In planning this study, it was anticipated that there would be periods of relatively little inter-lake movement bounded by transitional periods of increased inter-lake movement. The general approach was to define periods of relatively little inter-lake movement that were bounded by transitional periods, and to summarize data accordingly.

A fate assignment for each time period consisted of two components, a location label and a subscript. The location label was defined as: Upper Tangle Lake (UT), Round Tangle Lake (RT), Shallow Tangle Lake (ST), and Lower Tangle Lake (LT). Labels for Glacier Lake (GL), and Landmark Gap Lake (LGL) were excluded because no radio-tagged fish were ever found in either lake during this experiment. The subscripts were defined as:

1) Non-fishing mortality (NFM) – a fish located <u>within</u> the lake but was judged to be dead at the time of the survey being conducted. Death was observed directly (e.g. dead fish found on shore) or was deduced at the end of the study from a lack of movement. Fish with this fate were not used for calculating proportions for tracking surveys subsequent to the survey when mortality was assigned;

2) Fishery Mortality (FM) – a fish that was reported harvested within the lake of origin. Fish with this fate were not used in movement analyses for surveys subsequent to the survey it was known to be dead; and,

3) Unknown (U) – a fish whose fate is ambiguous for a particular time period. Fish with this fate were not used to calculate proportions for the period(s) they were not found. Because lake trout may spend considerable time in water too deep to be located during radio-tracking surveys (>5 m) several periods of this fate were anticipated.

4) At large (AL) – a fish that was not located during an aerial survey, but was located again during one or more subsequent surveys or by a radio-tracking station. The AL fate was a temporary assignment until completion of all surveys at which point fates were deduced and assigned.

Fish tracked during the spawning period were further categorized by denoting whether the fish was located on a verified spawning area (SA#) or not on a verified spawning area (Not SA). Spawning areas were numbered and the appropriate designation was assigned to the subscript at the completion of the study. A fate history was prepared for each radio-tagged lake trout (Tables 2 and 3).

Table 2.–Catch statistics and final fates of radio-tagged lake trout in Tangle Lakes, 2004–2005. The codes used for Final Fate are explained on page 24.

Date of Capture	Code	Length (mm FL)	Location Tagged	Gear Type	Last Known Location	Date at Last Location	Final Fate
8/6/2004	11	585	Round	Jug line	Round	8/6/2004	NFM[a]
8/6/2004	12	500	Round	Jug line	Round	9/21/2005	Live
8/8/2004	13	548	Round	Jug line	Round	9/27/2005	Live
8/6/2004	14	521	Round	Jug line	Round	9/28/2005	Live
8/6/2004	15	525	Round	H&L	Round	10/10/2004	FM
8/6/2004	16	541	Round	Jug line	Round	6/14/2005	U
8/6/2004	17	495	Round	Jug line	Round	8/6/2004	NFM[a]
8/8/2004	18	490	Shallow	H&L	Round	9/22/2004	U
8/6/2004	19	542	Round	H&L[b]	Round	8/23/2005	Live
8/8/2004	20	464	Shallow	H&L	Round	9/22/2004	U
8/8/2004	21	545	Shallow	Gillnet	Round	5/23/2005	U
8/9/2004	22	480	Shallow	Jug line	Shallow	5/23/2005	Live
8/10/2004	23	460	Upper	H&L	Upper	9/23/2005	U
8/10/2004	24	470	Lower	Gillnet	Lower	9/26/2005	U
8/10/2004	25	502	Lower	H&L	Lower	9/26/2005	Live
8/11/2004	26	651	Lower	Jug line	Lower	9/27/2005	Live
8/11/2004	27	530	Lower	Jug line	Lower	8/8/2004	NFM[a]
8/11/2004	28	506	Lower	Jug line	Lower	5/23/2005	U
8/11/2004	29	649	Lower	Jug line	Lower	9/27/2005	Live
8/11/2004	30	556	Lower	Jug line	Lower	9/25/2005	Live
8/11/2004	31	540	Lower	Jug line	Lower	9/27/2005	Live
8/11/2004	32	631	Lower	Jug line	Lower	9/27/2005	Live
8/11/2004	33	543	Lower	Jug line	Lower	9/27/2005	Live
8/11/2004	34	504	Lower	Jug line	Lower	9/8/2004	AL
8/11/2004	35	778	Lower	Gillnet	Lower	9/27/2005	Live
8/11/2004	36	764	Lower	H&L	Lower	9/27/2005	Live
8/11/2004	37	566	Lower	H&L	Lower	5/23/2005	U
8/11/2004	38	521	Lower	H&L	Lower	8/8/2004	U
8/11/2004	39	490	Lower	H&L	Lower	9/8/2005	U
8/11/2004	40	571	Lower	H&L	Round	9/22/2004	U
8/11/2004	41	529	Lower	H&L	Lower	9/27/2005	Live
8/11/2004	42	460	Lower	H&L	Lower	9/27/2005	Live
8/11/2004	43	551	Lower	H&L	Lower	8/8/2004	U
8/13/2004	44	575	Round	Jug line	Round	9/21/2005	Live
8/13/2004	45	525	Round	Jug line	Shallow	9/21/2005	Live
8/13/2004	46	505	Round	Jug line	Round	8/6/2004	U
8/13/2004	47	628	Round	Jug line	Round	9/21/2005	Live
8/13/2004	48	510	Shallow	Jug line	Shallow	9/22/2005	Live
8/13/2004	49	539	Shallow	Jug line	Round	8/25/2005	FM
8/13/2004	50	490	Shallow	Jug line	Shallow	9/22/2005	Live

[a] Died immediately after surgery.

[b] Harvested by hook and line in Lower Tangle Lake on 6/24/2007.

Table 3.–Summary of fates of radio-tagged lake trout in the Tangle Lakes over five tracking periods in 2004 and 2005 Entries in bold denote at least one observed movement from one lake to another during the study. Codes used are explained on pages 23 and 24.

Code	Tagging Location	Aerial Survey Prespawning 04	Boat Tracking Spawning 04	Aerial Survey Break-up 05	Aerial Survey Prespawning 05	Boat Tracking Spawning 05
11	Round	RT$_{NFM}$	Removed	Removed	Removed	Removed
12	**Round**	**RT**	**RT$_{SA1}$**	**RT**	**ST**	**RT**$_{Not\ SA}$
13	**Round**	**RT**	**RT$_{SA1}$**	**ST**	**RT**	**RT$_{SA1}$**
14	Round	U	U	U	RT	RT$_{SA1}$
15	Round	RT	RT$_{Not\ SA}$	RT$_{FM}$	Removed	Removed
16	**Round**	**RT**	**RT$_{SA1}$**	**ST**	**U**	**U**
17	Round	RT$_{NFM}$	Removed	Removed	Removed	Removed
18	**Shallow**	**ST**	**RT$_{Not\ SA}$**	**U**	**U**	**U**
19	**Round**	**U**	**RT$_{SA1}$**	**RT**	**ST**	**RT$_{Not\ SA}$**
20	**Shallow**	**RT**	**RT$_{Not\ SA}$**	**U**	**U**	**U**
21	Shallow	ST	U	ST	U	U
22	**Shallow**	**RT**	**RT$_{Not\ SA}$**	**ST**	**ST**	**ST$_{Not\ SA}$**
23	Upper	UT	UT$_{Not\ SA}$	UT	UT	UT$_{Not\ SA}$
24	Lower	LT	LT$_{Not\ SA}$	LT	LT	LT$_{Not\ SA}$
25	Lower	U	U	U	LT	LT$_{Not\ SA}$
26	**Lower**	**U**	**U**	**ST**	**LT**	**LT$_{Not\ SA}$**
27	Lower	LT	LT$_{NFM}$	Removed	Removed	Removed
28	Lower	LT	LT$_{Not\ SA}$	LT	U	U
29	Lower	U	LT$_{Not\ SA}$	LT	LT	LT$_{Not\ SA}$
30	Lower	U	U	LT	U	U
31	Lower	LT	LT$_{Not\ SA}$	LT	LT	LT$_{Not\ SA}$
32	Lower	U	LT$_{Not\ SA}$	LT	U	LT$_{Not\ SA}$
33	Lower	U	U	U	LT	LT$_{Not\ SA}$
34	Lower	LT	U	U	U	U
35	Lower	LT	LT$_{Not\ SA}$	U	LT	LT$_{Not\ SA}$
36	Lower	LT	LT$_{Not\ SA}$	U	LT	LT$_{Not\ SA}$
37	Lower	LT	LT$_{Not\ SA}$	LT	U	U
38	Lower	U	U	U	U	U
39	Lower	U	LT$_{Not\ SA}$	U	LT	U
40	**Lower**	**RT**	**U**	**U**	**U**	**U**
41	Lower	LT	LT$_{Not\ SA}$	LT	LT	LT$_{Not\ SA}$
42	Lower	LT	LT$_{Not\ SA}$	LT	LT	LT$_{Not\ SA}$
43	Lower	U	U	U	U	U
44	**Round**	**RT**	**RT$_{SA1}$**	**ST**	**RT**	**RT$_{Not\ SA}$**
45	**Round**	**U**	**RT$_{SA1}$**	**ST**	**ST**	**ST$_{Not\ SA}$**
46	Round	U	U	U	U	U
47	**Round**	**U**	**U**	**ST**	**RT**	**RT**$_{Not\ SA}$

-continued-

Table 3.–Page 2 of 2.

Code	Tagging Location	Aerial Survey Prespawning 04	Boat Tracking Spawning 04	Aerial Survey Break-up 05	Aerial Survey Prespawning 05	Boat Tracking Spawning 05
48	Shallow	ST	$ST_{Not\ SA}$	ST	ST	$ST_{Not\ SA}$
49	**Shallow**	**ST**	**$ST_{Not\ SA}$**	**ST**	**FM**	**Removed**
50	**Shallow**	**U**	**RT_{SA1}**	**ST**	**RT**	**$RT_{Not\ SA}$**
Unknown		15	12	13	13	13
Same Lake as Tagging Location (live only)		20	21	17	18	20
Different Lake from Tagging Location		3	4	6	4	2
Dead/Removed		2	3	4	5	5
Total		40	40	40	40	40
p(moved)		0.09	0.12	0.39	0.39	0.14
V(p moved)		0.00	0.00	0.01	0.01	0.01
p(at large)		0.41	0.30	0.36	0.36	0.37

To further describe movements, the proportion of fish moving among lakes or among spawning areas between periods of interest were estimated from the movement of radio-tagged fish as follows:

$$\hat{p}_{moved} = \frac{x_{moved}}{n} \tag{1}$$

$$\hat{V}[\hat{p}_{moved}] = \frac{\hat{p}_{moved}(1-\hat{p}_{moved})}{n-1} \tag{2}$$

where:

$\hat{p}_{moved}$ = the proportion of lake trout that moved at least once among lakes (or spawning areas) between the periods of interest;

x_{moved} = all radio-tagged fish whose location label (or spawning area identifier) changed between periods of interest (does not include fish with NFM, FM, or U subscript for fate in the first period); and,

n = includes x_{moved} and fish whose location label did not change between periods (does not include fish with NFM, FM, or U subscript for fate in the first period).

Radio-tracking station data, and to a lesser degree multiple surveys during a single period, were examined to assess within period movement. Of particular interest was movement during the mid-summer period when fish are most vulnerable to harvest. The proportion of fish changing lakes at least once was calculated as:

$$\hat{p}_{moved,i} = \frac{x_{moved,i}}{n_i} \qquad (3)$$

$$\hat{V}\left[\hat{p}_{moved,i}\right] = \frac{\hat{p}_{moved,i}(1-\hat{p}_{moved,i})}{n_i - 1} \qquad (4)$$

where:

$\hat{p}_{moved,i}$ = the proportion of lake trout that changed lakes at least once during the period of interest; *i*;

$x_{moved,i}$ = all radio-tagged fish whose location label changed at least once during the period of interest, *i*, (does not include fish with NFM, FM, or U subscript for fate during the period); and,

n_i = includes $x_{moved,i}$ and fish whose location label did not change during the period of interest, *i*, (does not include fish with NFM, FM, or U subscript for fate during the period).

Length and sex composition of the catch was described, and capture location and gear used are reported. Empirical cumulative length frequency distributions were compared using Kolmogorov-Smirnov (K-S) 2-sample and Anderson-Darling k-sample tests (Scholz and Stephens 1987) to test for differences between gear types and among lakes for lake trout captured at the time of spawning.

RESULTS

2004 FIELD SEASON

Radio tag implantation

During August 2004, a total of 45 lake trout (350-778 mm FL) were captured in the four connected Tangle Lakes (20 in Lower Tangle Lake, 17 in Round Tangle Lake, seven in Shallow Tangle Lake, and one in Upper Tangle Lake). Two fish were inadvertently killed (from Round Tangle Lake) and one captured fish was too small to receive a radio tag (≤450 mm FL).

Forty of the 45 lake trout ≥450 mm FL (i.e., assumed to be sexually mature) were surgically-implanted with radio transmitters and released (20 from Lower Tangle Lake, 12 from Round Tangle Lake, seven from Shallow Tangle Lake, and one from Upper Tangle Lake; (Table 2)). Although approximately equal amounts of sampling effort in terms of time and gear were allocated to each lake, strict adherence to the minimum and maximum numbers per lake (i.e. between 5 and 14) was not possible due to a large variation in catch rates and because only one lake trout was captured in Upper Tangle Lake. However, transmitters were distributed in similar proportion to catches of lake trout ≥450 mm FL, which seemed to be a reasonable approximation of their true distribution among the four lakes.

Aerial surveys

The first tracking flight occurred on September 8, 2004, just prior to field sampling to search for spawning sites. Initially, two radio-tagged lake trout failed to move from their original capture location. These fish either did not survive the surgery or quickly expelled their radio tag after surgery, and in either case, were labeled tagging mortalities (NFM) leaving 38 lake trout presumed alive during the first tracking flight. During this flight, 20 fish were located in the same lake in which they were tagged, three were found in a different lake from where they were tagged, and 15 were not located (Table 3). No fish were located in Glacial or Landmark Gap lakes, and no fish moved in or out of Upper Tangle Lake. The 15 fish that were not located were likely in water too deep to be located with the receiver.

Fall boat surveys and sampling

During early September 2004, sampling occurred from 2100 to 0200, for 11 days (September 9 to 22). On two days, sampling was either terminated early or cancelled due to inclement weather. Boat surveys (visual and tracking) in Upper and Shallow Tangle lakes revealed little to no suitable spawning habitat, and while spawning was known to be occurring at the previously documented spawning area in Round Tangle Lake, no aggregations of lake trout were found. In Lower Tangle Lake, the four radio-tagged fish aggregated were identified in the inlet stream just upstream from the lake entrance (63.129825° N x 145.972461° W). However, due to the low water in the stream, crewmembers were unable to boat to this location for a visual inspection and sampling. In Lower Tangle Lake, no fish (individual or aggregations) were found at areas of apparently suitable spawning habitat. A brief summary of the boat tracking survey is as follows:

- of the 40 lake trout fitted with transmitters, 28 were located and 12 were not;
- of the 28 located fish, 21 were found in the same lake in which they were tagged;
- six of the seven lake trout found on the spawning ground in Round Tangle Lake were tagged in Round Tangle Lake, the other was tagged in Shallow Tangle Lake;
- no fish from Round Tangle Lake were found in Lower Tangle Lake, and vice versa;
- no fish from Shallow Tangle Lake were found in Lower Tangle Lake, and vice versa;
- four fish tagged in Lower Tangle Lake were located in the stream just upstream from the lake but could not be visually verified;
- only one spawning aggregation of lake trout was visually observed (in Round Tangle Lake), although it appears, based on the discovery of four radio-tagged fish upstream of the Lower Tangle Lake inlet, that spawning may occur in the creek;
- three fish were assumed dead; two remained very close to original release location and one transmitter was found washed ashore in Lower Tangle Lake;
- one radio-tagged fish was harvested soon after this event and removed from the study; and,
- the largest number of radio-tagged fish located on the spawning area in Round tangle Lake was seven fish.

In Round Tangle Lake, 49 fish (36 males, 10 females, and three that could not be identified to sex) were captured from the only identified spawning location using a beach seine on 9, 10, 16, and 22 September. Of these, one was a radio-tagged fish that was originally caught in Round Tangle Lake on August 6. These fish ranged in length from 378 to 685 mm FL, but only fish 420 mm FL and larger were found to be sexually mature. Large aggregations of fish were not observed, nor were ripe or spawning fish sampled until 22 September, when most of the fish were seined (n = 31). "Blind" seine hauls set over potential spawning substrate in Lower Tangle Lake captured no fish.

Tracking stations

The receivers from the three tracking stations were retrieved in December 2004. The dates of operation for all three stations varied (Figure 3). A summary of data collected through November 2004 (when solar radiation became insufficient to charge the batteries) is as follows:

Station 1 (between Upper and Round Tangle lakes) – This station operated from 23 August to 28 November 2004. During this time, no fish passed the station in either direction, nor were any detected coming close to the station. Based on this information and results from aerial and boat tracking, it appeared unlikely that regular movement occurs between these lakes and therefore this tracking station was removed in May 2005 to be used on another research project. However, Upper Tangle Lake was monitored via aerial surveys and boat-tracking during spawning season in 2005.

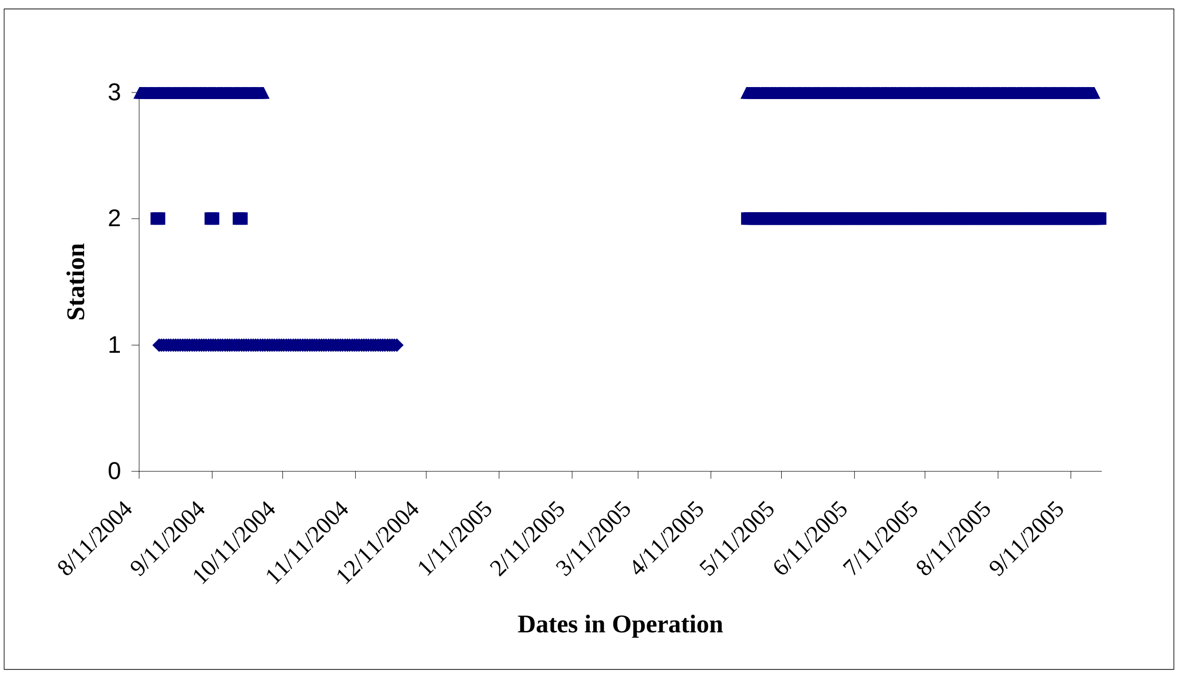

Figure 3.–Dates of operation for the three tracking stations. Station 1 was between Upper and Round Tangle Lake, Station 2 was between Round and Shallow Tangle Lake, and Station 3 was between Shallow and Lower Tangle Lake.

Station 2 (between Round and Shallow Tangle lakes) – This station was only operable for five days between 23 August and 23 September 2004 due to a malfunction within the receiver. The receiver at this station had a faulty internal battery, and consequently would not store a charge from the solar panel. Recorded movements included:

- three fish tagged in Round Tangle Lake were detected close to the upstream antenna (closest to Round Tangle Lake) on 22 September at 0100 but did not pass the station; and,
- one fish tagged in Shallow Tangle Lake moved up into Round Tangle Lake (date unknown) and back down into Shallow Tangle Lake on 10 September.

Station 3 (between Shallow and Lower Tangle lakes) – This station operated successfully from 23 August to 2 October 2004. It is believed that the proximity of a large hill to the southwest of the station kept it from receiving sufficient sunlight to operate later. Recorded movements included:

- one fish tagged in Shallow Tangle Lake was recorded by the upstream antenna for nearly two hours on 4 September but did not appear to pass the station;
- one fish tagged in Shallow Tangle Lake passed the station going towards Lower Tangle Lake on 24 September;
- one fish tagged in Lower Tangle Lake was recorded by the upstream antenna almost continuously for 10 days from 15 September through 25 September;
- three fish, all tagged in Shallow Tangle Lake, were recorded on the downstream antenna intermittently for several days from 14 September through 29 September; and,
- no fish tagged in Round Tangle Lake were observed passing or nearing this station.

Receivers were returned to Stations 2 and 3 on 26 April 2005 and were operating correctly. Data from stations 2 and 3 were retrieved prior to sampling operations on 9 September 2005, and the stations were removed 23 September 2005.

2005 FIELD SEASON

Aerial surveys

The first tracking event of the season was an aerial survey on 23 May 2005 just prior to breakup (Table 3). A brief summary of the aerial survey is as follows:

- of the 36 lake trout fitted with transmitters and believed to be alive, 23 were located and 13 were not;
- of the 23 located fish, 17 were found in the same lake in which they were tagged;
- six fish were found in lakes different than the one in which they were located during boat-tracking in September 2004; and,
- no radio-tagged lake trout were located in Glacier or Landmark Gap lakes.

On 21 September, just prior to the fall sampling event, an aerial tracking flight was flown over Upper, Round, Shallow, and Lower Tangle lakes. One radio-tagged fish had been caught and harvested from Round Tangle Lake on 29 August and was removed from the study, leaving 35 radio-tagged fish potentially alive. A brief summary of the aerial survey is as follows:

- of the 35 lake trout potentially alive, 22 were located and 13 were not;
- of the 22 located fish, 18 were found in the same lake in which they were tagged;
- four fish were found in lakes different from where they were tagged;
- seven fish were found in lakes different from where they were located during aerial tracking surveys in May 2005; and,
- no additional fish were presumed dead or known to be harvested.

No radio-tagged lake trout were located in either Glacier or Landmark Gap lakes during the two occasions these lakes were aerial surveyed in 2005.

Fall boat surveys and fish sampling

From 21 to 29 September 2005, 250 unique lake trout were captured and sampled (221 from Round Tangle Lake, 29 from Lower Tangle Lake). All lake trout sampled from Round Tangle were captured on the known spawning site using beach seines, while all fish in Lower Tangle were captured using gillnets, jug lines, and hook-and-line.

In Upper Tangle Lake, crews spent three hours each night for two nights searching for spawning aggregations and radio-tagged fish. The lone fish that was tagged in August 2004 was located, and no evidence of a spawning site was seen.

In Round Tangle Lake, only one spawning site was ever located. From this location, 221 fish (176 males, 37 females, and 8 unknown) were captured using a beach seine on 21, and 25–29 September. Mean length of captured fish was 478 mm FL (SD = 70) and lengths ranged from 283 to 750 mm FL. Of these, two were radio-tagged fish that were originally caught in Round Tangle Lake on 6 and 8 August 2004, and 15 fish were originally caught and Floy-tagged in September 2004. Some fish were captured multiple times throughout the six seining occasions between 21 and 29 September: forty-two fish were caught twice, 18 caught three times, three caught four times, and one caught five times. No fish Floy-tagged in Upper, Shallow, or Lower Tangle lakes were captured on the spawning location in Round Tangle Lake in 2005. The largest aggregations of fish seen and largest numbers captured occurred between 25 and 27 September, when 61, 59, and 57 fish were captured on consecutive nights. By the 29th, spawning appeared to be nearly finished because only 12 fish were caught and few fish were seen nearby. Generally, fish did not appear on the spawning grounds in large numbers before 2200 and by 0100 most spawning activity had ceased for the night.

In Lower Tangle Lake during 26–29 September, 29 lake trout were captured (18 females, 1 male, 10 unknown) and of these, three fish had been radio-tagged in Lower Tangle Lake in August 2004. The mean length of these fish was 565 mm FL (SD = 73), and lengths ranged from 370 mm to 697 mm FL. Of the 29 fish captured, 11 appeared to be spent females, two were ripe females, one was a ripe male, and 15 were of unknown sex. No spawning aggregations or groups of fish were seen with spotlights or located with the receiver, nor was any evidence of spawning (e.g., eggs spread over substrate) detected by the divers.

In Lower Tangle Lake in 2005, four radio-tagged fish were located in the inlet creek above the lake both during the day and at night over a three-day period. Based on this observation, it was suspected that perhaps spawning was occurring in the creek and therefore divers searched for lake trout eggs and spawning sites in the lower 0.2 km of the outlet. No groups of fish were seen, nor was any evidence of spawning (i.e.; eggs lying on rocks). At night, the crew observed several lake trout actively chasing smaller fish in the creek and often splashing through shallow water near the shore in attempt to catch them. No spawning behavior was observed.

Attempts to locate spawning locations in both Shallow Tangle and Upper Tangle Lake via visual inspection by boat with spotlights and trained observers as well as radiotelemetry were unsuccessful in both 2004 and 2005, suggesting that spawning in Upper and Shallow Tangle lakes does not occur.

Tracking stations

The receivers from the two tracking stations were retrieved in December 2005. A summary of data collected through September 2004 (when the project was completed and the stations were removed) is as follows:

Station 2 (between Round and Shallow Tangle lakes) **–** This station was in operation between 26 April and 23 September 2005. During this time, nine different fish had passed by this station, and three of these fish had done it multiple times. Movements include:

- one fish tagged in Round Tangle Lake moved from Round Tangle to Shallow Tangle Lake on 11 June;
- one fish tagged in Round Tangle Lake moved from Shallow Tangle back in to Round Tangle Lake on 14 June;
- one fish tagged in Round Tangle Lake moved from Shallow Tangle to Round Tangle Lake on 23 August (this fish had gone from Shallow Tangle to Lower Tangle on 22 May and back into Shallow Tangle on 16 June);
- one fish tagged in Round Tangle Lake moved from Round Tangle to Shallow Tangle Lake on 14 June, and back to Shallow Tangle Lake on 24 August;
- one fish tagged in Round Tangle Lake moved from Shallow Tangle to Round Tangle Lake on 15 May, back to Shallow Tangle on 16 June, and back into Round Tangle Lake on 20 September;
- one fish tagged in Round Tangle Lake moved back and forth between Shallow Tangle and Round Tangle seven times between 2 May and 21 September ending up in Round Tangle;
- one fish tagged in Shallow Tangle Lake moved from Round Tangle to Shallow Tangle Lake on 8 July and back into Round Tangle Lake on 8 August;
- one fish tagged in Round Tangle Lake moved to Shallow Tangle Lake on 14 June; and,
- one fish tagged in Shallow Tangle Lake moved from Shallow Tangle to Round Tangle Lake on 15 August, and was harvested by a sport angler from Round Tangle Lake on 29 August.

Objective 1

Identification of spawning areas that accounted for 80% of the spawning population of lake trout within the four connected Tangle Lakes with 90% confidence using radiotelemetry was not met because the data was inconclusive. Only one spawning location was found (on Round Tangle Lake), and no fish tagged in a lake other than Round Tangle were ever captured there. In addition, never were there enough radio-tagged fish located during any event to meet the precision criteria for this objective. During spawning in 2004, seven of the 25 radio-tagged fish located (28%) were heard on the spawning site on Round Tangle. In addition, three of the radio-tagged fish located in Round Tangle during spawning (but not on the spawning site) in 2004 were tagged in a different lake (Shallow Tangle; Table 2). In 2005, just 2 of the 22 radio-tagged fish located during spawning were detected on the spawning site, both tagged in Round Tangle in 2004. The known spawning site in Round Tangle Lake is likely the major, and perhaps only, spawning location for lake trout in Round Tangle. The absence of any radio- or Floy-tagged fish from Shallow or Lower Tangle during any of the fall sampling at this site suggests that other important sites exist but were not found.

Objective 2

Seines were determined to useful to capture lake trout in only one spawning location that was identified in Round Tangle Lake, where the shoal was shallow enough (≤1.5 m) and close enough to the shore to effectively use a beach seine to capture fish. The effectiveness of the seine was limited by the large size of the spawning shoal which resulted in a looser aggregation of fish than compared to nearby lakes (e.g., Sevenmile Lake and Paxson Lake). The shoal extending ~60 m from shore is larger than the area covered by one seine haul. To reach the shoal, the seine must first set relatively far offshore (e.g. 9 m) and the boat must be driven approximately 45 m out before attempting to return to shore, leaving considerable gaps where fish could escape. Gillnets would be effective in supplementing catches if needed, and would be most effective set outside the perimeter of the seine area before the seine is deployed, a strategy use successfully in other lakes with a large spawning area (Parker et al. 2001).

The difference in seine catches between 2004 and 2005 is attributed to when the seine hauls were conducted relative to peak spawning. In 2005, sampling began 10 days later, and catches were higher (221 fish in 2005 vs. 49 fish in 2004).

Objective 3

Descriptions of locations and movements radio-tagged lake trout were limited by faulty tracking stations and the inability to locate radio-tagged fish in deep water (e.g. >5 m). The proportion of radio-tagged fish believed to be alive that were not found during an aerial or boat tracking survey ranged from 0.30 to 0.41 (Table 2). The majority of recorded movements between lakes consisted of exchanges between Round Tangle and Shallow Tangle lakes, with five fish tagged in Round Tangle moving into Shallow Tangle, and five fish tagged in Shallow Tangle moving in to Round Tangle (Table 2 and Appendix A). In addition, it appears that lake trout had moved between Round Tangle and Shallow Tangle during the months that the tracking station was either inoperable or not deployed (early-October 2004 through late-April 2005) because several fish that were found in one lake just after freeze-up were found in the other lake during the aerial survey the following spring (Appendix A). Open water was observed in the creek between the lakes that appeared deep enough for fish passage both when the receivers were retrieved for data collection (December 2004) and when they were redeployed prior to break-up (April 2005), so this winter movement seems plausible.

PROJECT TASKS

Relative to Tasks 1 and 2, a total of 314 unique lake trout (43 in August 2004, 48 in September 2004, and 223 in September 2005) were captured and affixed with a Floy FD-94 anchor tag. Of these, 202 fish were males, 63 were females, and 49 were of unknown sex. The mean length of males was 560 mm FL (SD = 78 mm), and females was 520 mm FL (SD = 70 mm).

Since this experiment ended in fall 2005, anglers have returned five tags from harvested lake trout in the Tangle Lakes. Two of these fish were tagged in Round Tangle Lake and harvested from Lower Tangle Lake, one was tagged and harvested from Round Tangle and two were tagged and harvested from Lower Tangle.

Relative to Task 3, it does not appear that a successful stock assessment can be conducted on lake trout in the connected Tangle Lakes until all of the major spawning sites are located, particularly sites where fish from Lower and Shallow Tangle lakes spawn. Estimate abundance for lake trout generally requires attaining a representative sample of the entire spawning population, which is not possible if fish express fidelity to unknown spawning areas.

Relative to Task 4, insufficient data was collected for an adequate assessment. Ideally, the results of this project would have provided more information regarding inter-lake movement, which could help determine whether or not the current harvest reporting (i.e.; all lakes classified as one system in the SWHS) is sufficient. However, it is probably safe to assume that few, if any, lake trout reported caught or harvested came from Upper Tangle Lake, and based upon the difficulty of access, Lower Tangle Lake does not contribute significantly to the reported catch and harvest.

Relative to Task 5, no additional work is needed to assess the interdependency between Tangle Lakes and its neighboring lakes, Glacial and Landmark Gap. Based on observations during the aerial and boat surveys, the connecting creeks were too small, steep, and long to have any meaningful exchange of larger lake trout (e.g.≥age 3), but may provide reasonable passage of smaller juveniles (e.g. age-0 and -1 fish).

DISCUSSION

This study was unable to document all major spawning areas. A sample size of 36 live radio-tagged fish (the number presumed alive prior to spawning in 2004) at the time of spawning should have been sufficient to document suspected major spawning area(s) in Lower Tangle Lake, or any spawning in Shallow Tangle Lake. The reproductive condition of the 29 fish captured in Lower Tangle Lake in fall 2005 showed 11 as spent females, two as ripe females, and one as a spent male. This, along with having never detected a lake trout from Lower Tangle Lake on or near the spawning site on Round Tangle suggests that at least one significant spawning site was not located during experiment. Therefore, spawning must have occurred somewhere between the falls just below the Lower Tangle Lake outlet and downstream of the tracking station operating just above the outlet of Shallow Tangle Lake (Figure 1). Lower Tangle, based on catch rates in August 2004, appeared to have at least as many fish in it as Round Tangle and no spawning sites for these fish were positively identified. Initially, it was anticipated that the divers would be limited to surveying the 14 locations that appeared to have suitable spawning habitat (Figure 2). However enough compressed air for diving remained after these sites were surveyed (no evidence of spawning was observed) that the entire perimeter of the lake was surveyed, even locations with what would be considered poor habitat for spawning (i.e. sandy or muddy substrate, emergent vegetation, and insufficient depth), and still no evidence of spawning was detected.

It appeared that lake trout in Lower Tangle Lake may spawn in one of three suspect locations:

1) offshore on a shoal or in deeper water in Lower Tangle Lake, although we never detected concentrations of radio-tagged lake trout visually or with the receiver, nor did we capture a group of lake trout at a time with gillnets that would suggest a spawning concentration of fish; 2) in the creek just above the inlet to Lower Tangle (Figure 2) although the divers searched the lower one km of the creek (above which was a long riffle that was too shallow and unsafe for boating and did not appear to contain depth for lake trout spawning habitat) and saw no fish; or, 3) in the outlet or creek of Lower Tangle between the lake and the falls approximately 1.5 km from the lake outlet, which was not surveyed. The possibility exists that the divers actually surveyed locations along the lake shore where lake trout do indeed spawn but failed to detect evidence of spawning. This failure can be possibly attributed to eggs settling into the interstices of the rocks making them invisible. If this were the case, then lake trout in Lower Tangle Lake had finished spawning somewhat earlier than the lake trout in Round Tangle Lake because the divers were surveying Lower Tangle Lake during peak spawning in Round Tangle Lake (22–24 September). This appears unlikely because the abiotic factors that trigger spawning (such as air and water temperature thresholds, wind speed and direction) should not be markedly different between lakes given their common water source and distance from each other (approximately 4 km).

Lake trout in Lower Tangle Lake possibly spawn in the running waters of the inlet or outlet stream. Lake trout spawning in rivers has been documented in Quebec, Alberta, the Northwest Territories, and in inlet streams of Lake Superior (Balon 1980; George Low, Fisheries Manager, Department of Fisheries and Oceans, Northwest Territories, Canada, personal communication). In Swan Lake, Alberta, a lake trout spawning site is located in the lake outlet approximately 400 m downstream from the lake at depths of 15 to 50 cm (Paterson 1968). In Des Cedres Brook, Quebec, lake trout spawn in the stream that connects two lakes (Seguin and Roussel 1968). This stream is approximately 450 m in length, varies in width from 4.6 m to 12.2 m, and the actual spawning area is about 75 m long with depths of 30 to 60 cm (Seguin and Roussel 1968). In general, bottom materials in stream spawning beds appear to be smaller than those in lakes, possibly because current can more effectively keep the bottom clean of mud and silt than can wave action in lakes (Balon 1980). Based on these studies, the stream that connects Shallow and Lower Tangle Lake could provide suitable spawning because it is composed of both swift, shallow glides and large, deep pools 3 m or more in depth, with the deeper pools being closer to the inlet of Lower Tangle Lake. It is likely that current flows through the deeper sections of the stream throughout the year (open, running water was observed between Round and Shallow Tangle Lake in both January and March 2006) and these areas may provide more suitable spawning habitat than is available in the lake. The presence of four radio-tagged fish in the creek during September 2005 may also be linked to spawning activity in the creek, although these fish were too far upstream of the lake to be reached by boat to confirm their exact location.

The depth of the spawning location in Round Tangle Lake was shallow enough for a seine to be effective. A longer seine or two seines fished simultaneously may have increased catches.

However the proportion of fish caught more than once during the sampling in September 2005 (69 of the 221 unique fish were captured more than once over six nights of sampling, with three fish being caught four times and one fish being caught five times) indicated the procedures used to capture spawning fish worked well. Recently, large fyke traps with long center leads set perpendicular to the shoreline directly in front of the spawning site have worked well in some lakes for catching lake trout (April Behr, Fisheries Biologist, ADF&G, Fairbanks, personal communication). These traps can be set to fish 24 hours/day and appear to cause minimal stress to the fish if checked regularly, and may work well in Round Tangle Lake.

The low catches in Upper Tangle Lake (i.e. one fish) strongly suggested that the population was very small and was consistent with Burr (1989). In 1988, the abundance of lake trout ≥ 250 mm FL was 211 fish (SE = 33) and the abundance of lake trout 450 mm FL and greater was 96 fish (SE = 17) or just 0.6 fish per hectare (Burr 1989). The author suggested that the dearth of lake trout in Upper Tangle Lake may be due in part to overexploitation, for the Tangle Lakes are located in one of the interior's most popular recreation areas and Upper Tangle Lake is right off the road and has a boat launch. In addition, the author mentioned that while Upper Tangle Lake has a similar surface area size as Round and Lower Tangle Lake, it appears to have less deep water refugia and therefore less effective available habitat (Burr 1989).

The information necessary to apply the LA model (e.g. summing surface individual yield estimates or calculating a single estimate for all lakes) to estimate sustainable yield of lake trout in the connected Tangle Lakes was not attained in this study, however there were a few insights regarding movements gained from this project. First, when applying the LA model to lake trout in the connected Tangle Lakes, one could argue to not include the surface area of Upper Tangle Lake in the estimate for sustainable yield. Upper Tangle Lake appears to have a very small population of lake trout, and there is negligible, if any, interchange of fish with the other three lakes. Second, the minimal exchange between Lower Tangle Lake and the upper lakes (Shallow and Round) suggests that Lower Tangle Lake may be treated as a separate population. Only one of the 19 live radio-tagged fish Lower Tangle was ever heard near Round Tangle Lake, and no fish Floy-tagged in Lower Tangle Lake have been captured or harvested elsewhere although two Floy-tagged fish marked in Shallow Tangle were captured by anglers in Lower Tangle Lakes. The positive documentation of a spawning area in Lower Tangle Lake would support the argument of an independent stock. Third, virtually all of the recorded movement of Floy- and radio-tagged lake trout in this study consisted of periodic interchange of fish between Round and Shallow Tangle lakes suggesting that these two lakes comprise a single stock. Lastly, the degree of exchange of juvenile lake trout (e.g. age-1 fish) among the four lakes was not addressed, which could be significant.

Future research should be concentrated on the population of fish in Lower Tangle Lake. Lower Tangle Lake may have the highest abundance of fish of all four connected lakes based on the catch rates in August 2004 sampling. Finding spawning locations should the first step into designing stock-assessment experiments to estimate abundance or to sample fish weights for the LA model if Lower Tangle Lake is treated as a separate stock.

Recently, research using acoustic tags has been used to gain fine-scale movement and habitat use information from lake trout (Blanchfield et al. 2005; Mackenzie-Grieve and Post 2006). Acoustic tags are small sound-emitting devices that permit remote tracking of fish in three dimensions. Unlike radio tags, which are typically only detected within the first 6 m (20 ft) of the surface, acoustic fish tags detect fish movement anywhere in the region of interest within the detection range of the tag up to 1,000 m in freshwater, and have a battery life of up to four years. Acoustic tags have the benefit of providing similar location information as do radio-transmitters but are not constricted by depth of the fish. The use of acoustic tags would be particularly helpful in Lower Tangle Lake where there is considerable deep water (>6 m). Seven of the 19 presumed live radio-tagged fish that were not found during any tracking event may have been located if acoustic tags had been used. In addition, if the acoustic-tagged fish can be recaptured, temperature and depth information archived in the tag can be recovered.

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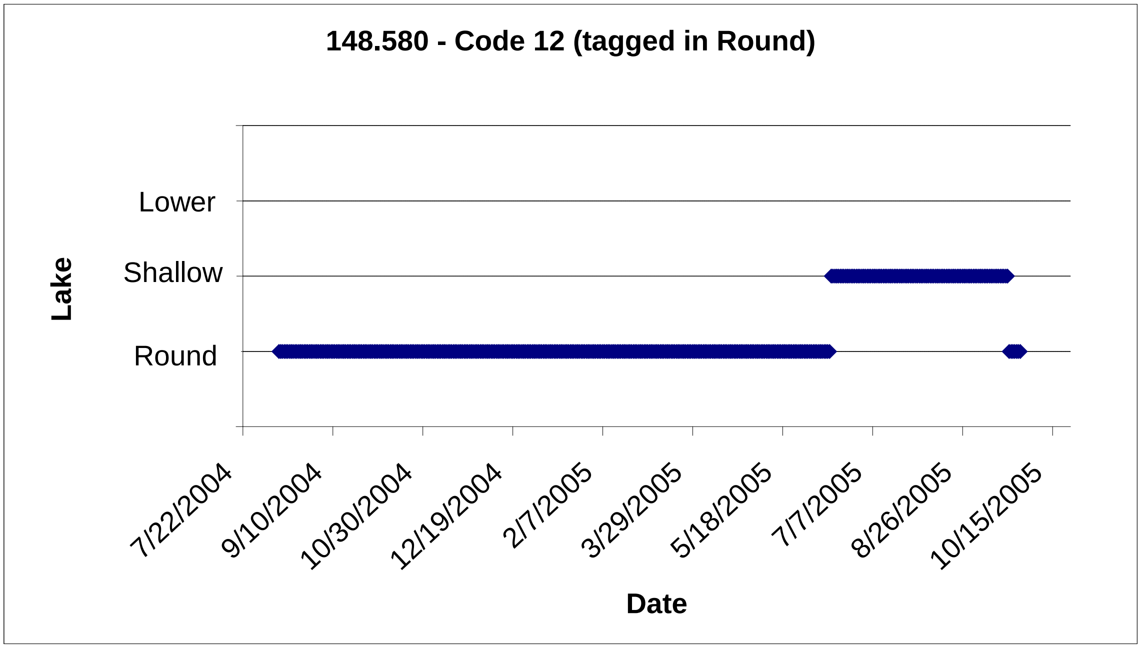
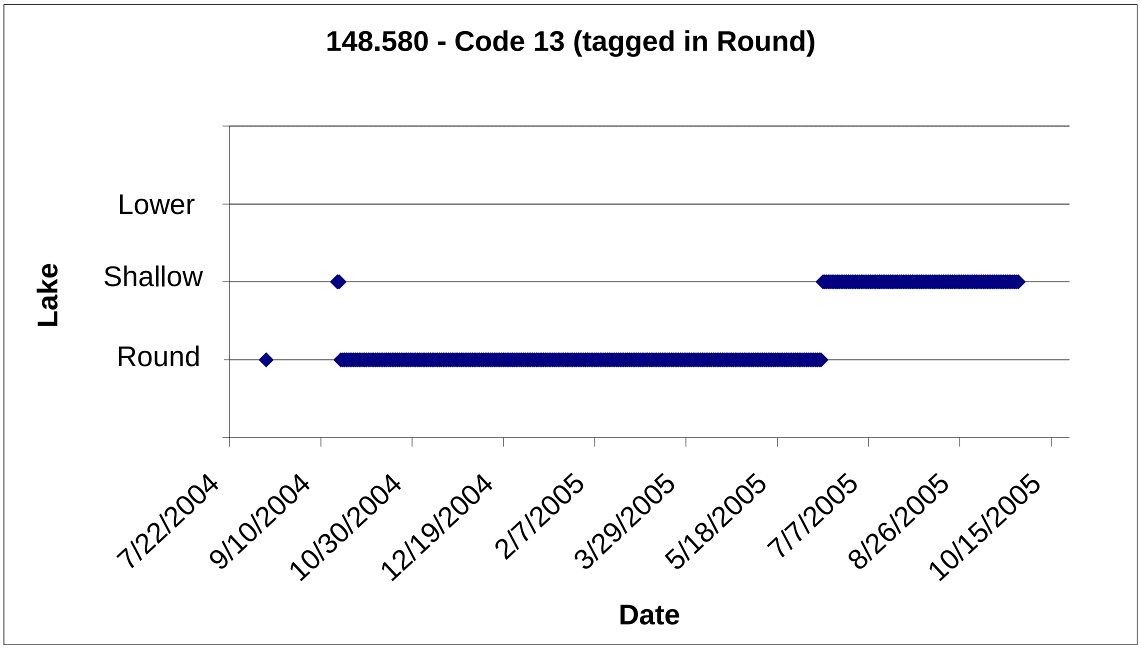
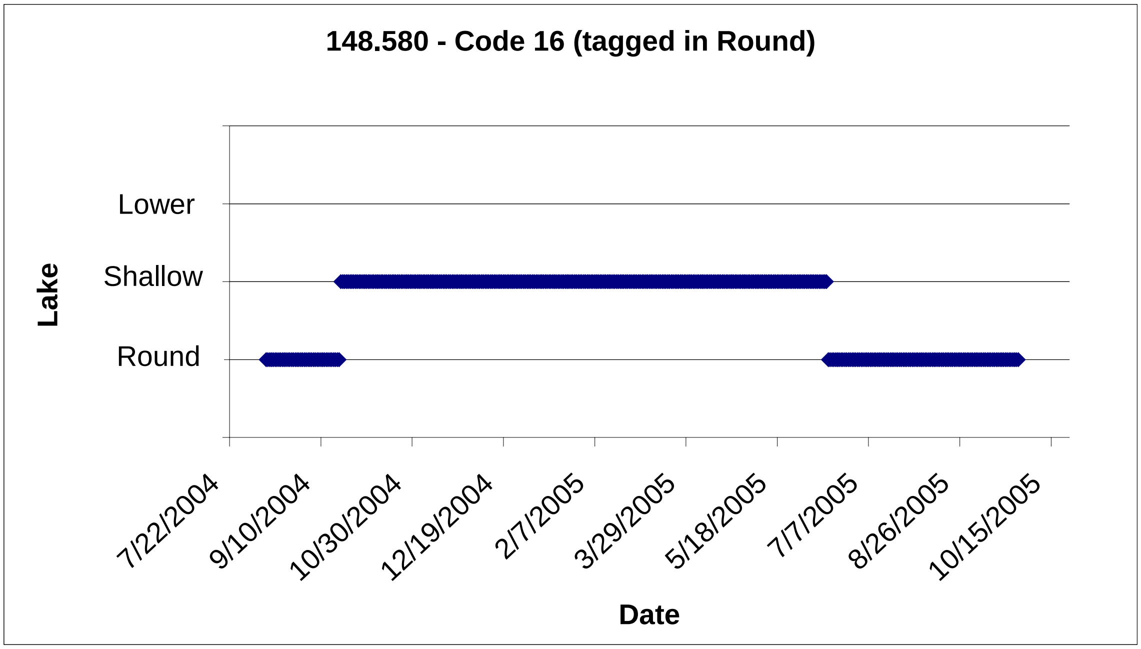
APPENDIX A

Appendix A1.–Suspected locations and timing of movements for 14 radio-tagged lake trout based on data collected from tracking stations, aerial tracking, and boat tracking surveys. Gaps represent periods of unknown location status. Each lake trout was surgically implanted with LOTEK (MCFT-3A) radio transmitters with unique codes spread over four frequencies.



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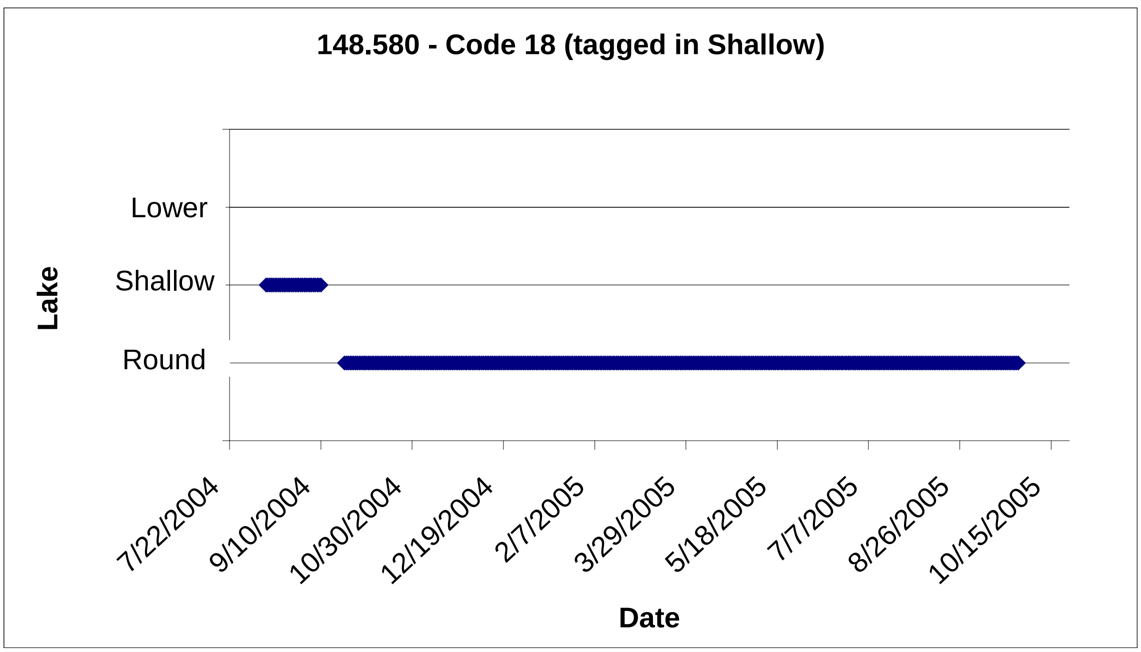
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date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Lower
Shallow
Round
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9/10/2004
10/30/2004
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8/26/2005
10/15/2005
Date

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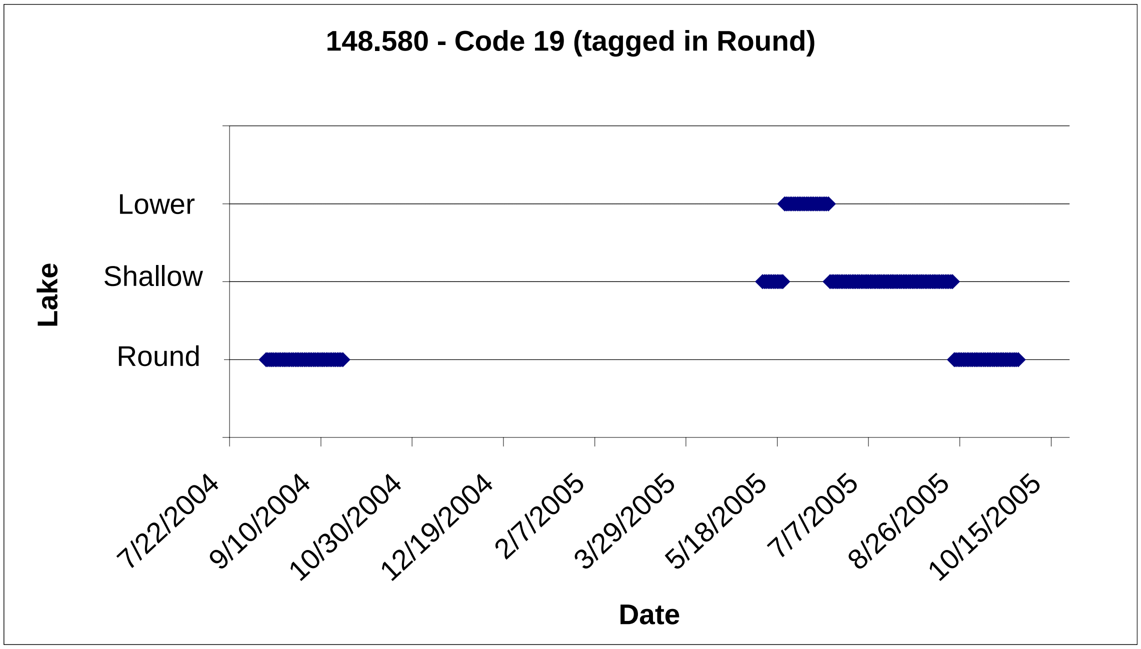
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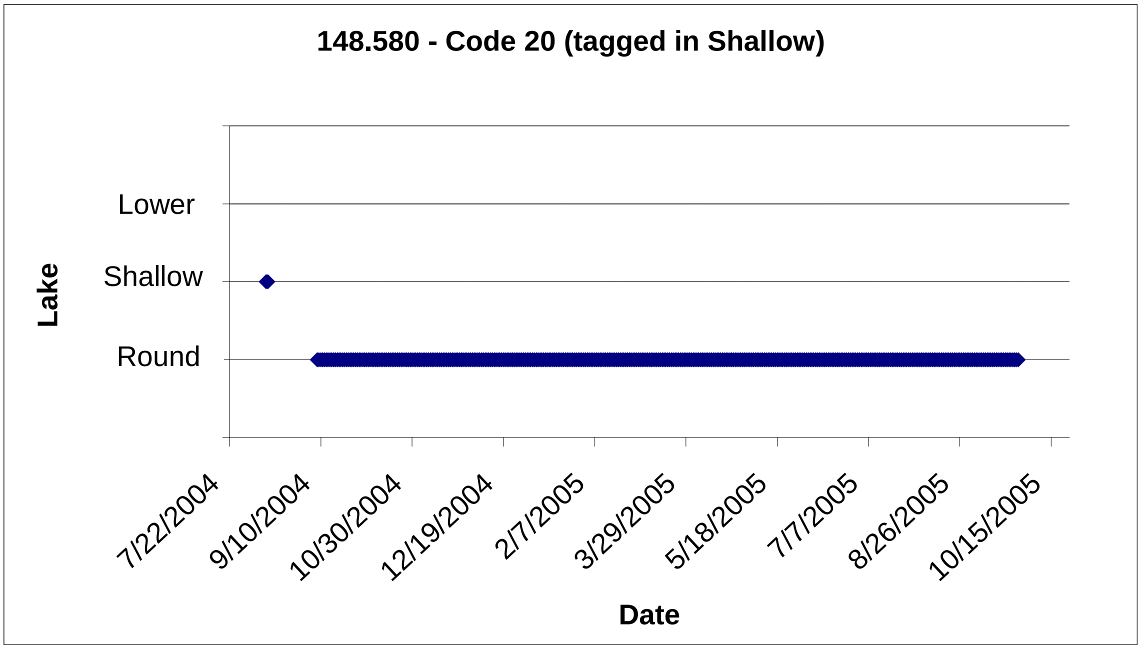
Date


148.580 - Code 20 (tagged in Shallow)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

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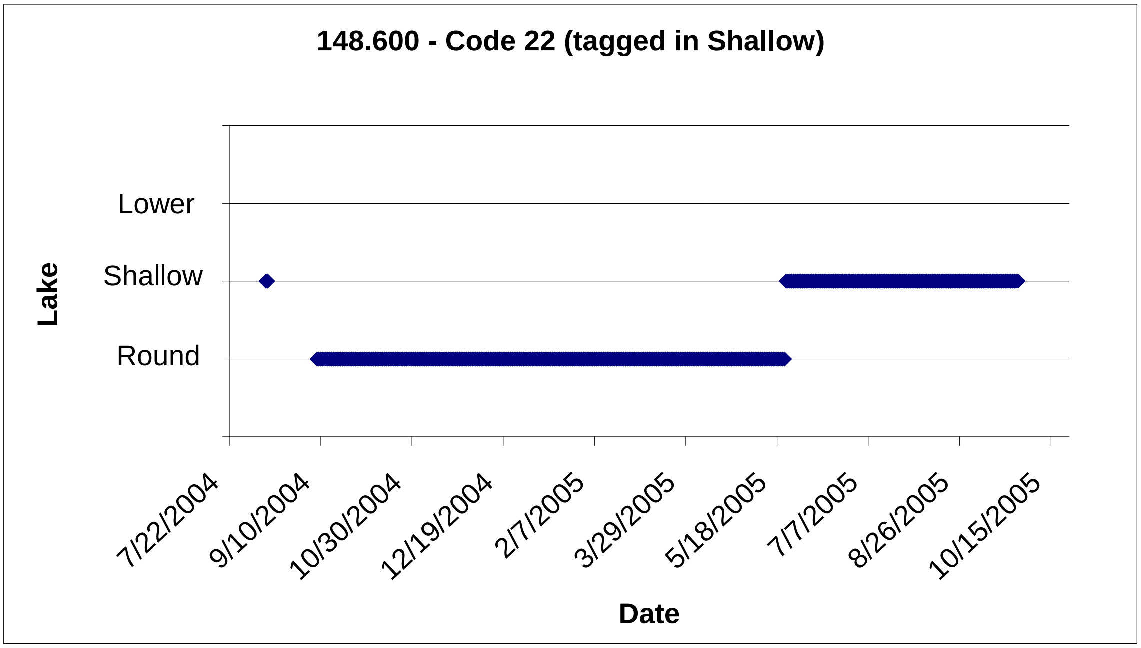
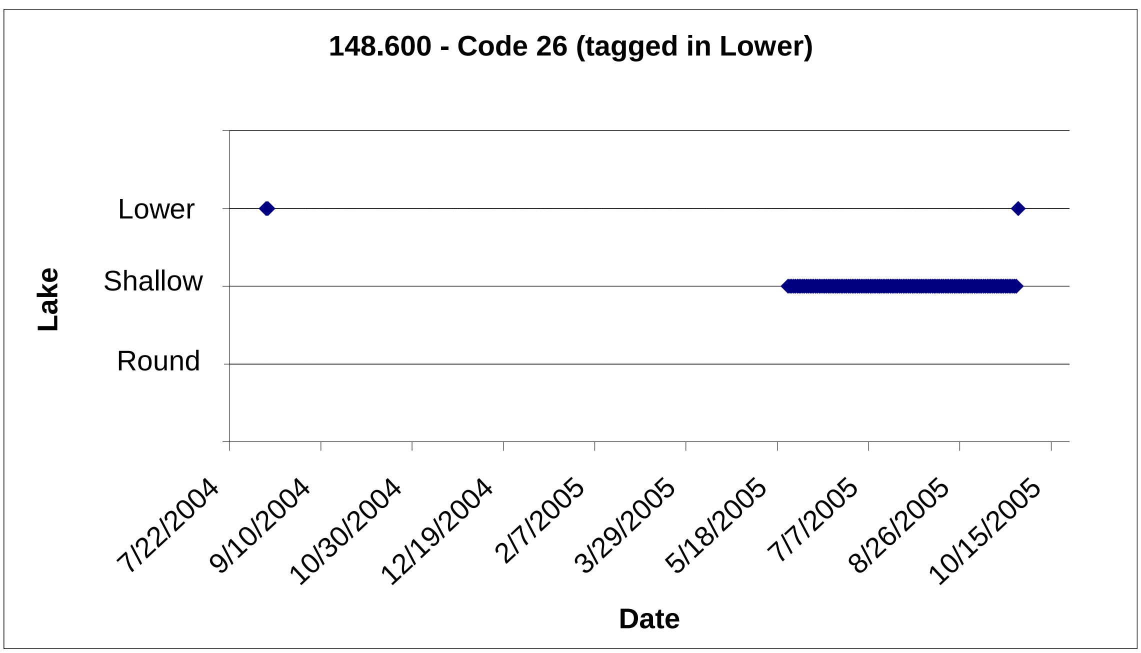
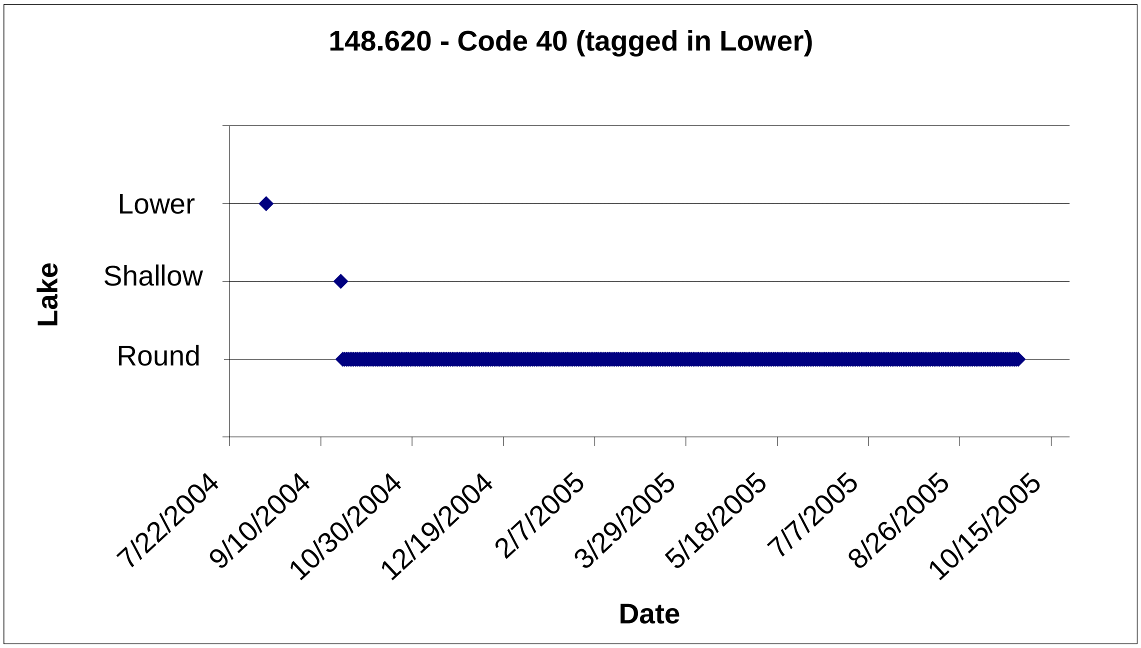
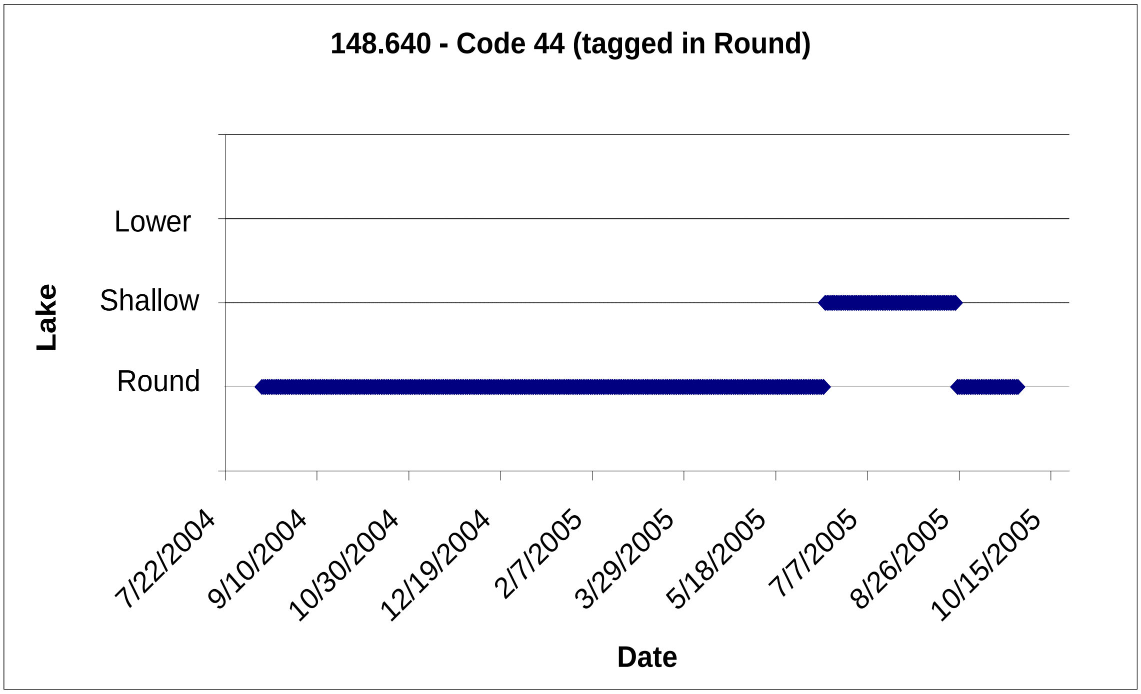

148.600 - Code 22 (tagged in Shallow)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

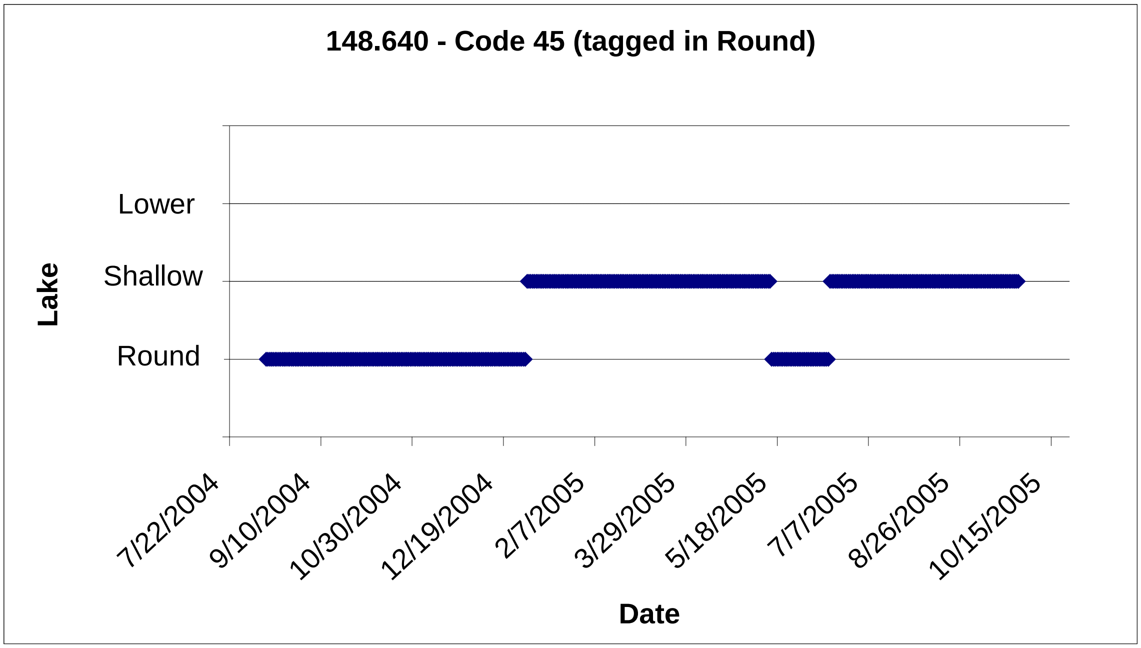

148.600 - Code 26 (tagged in Lower)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

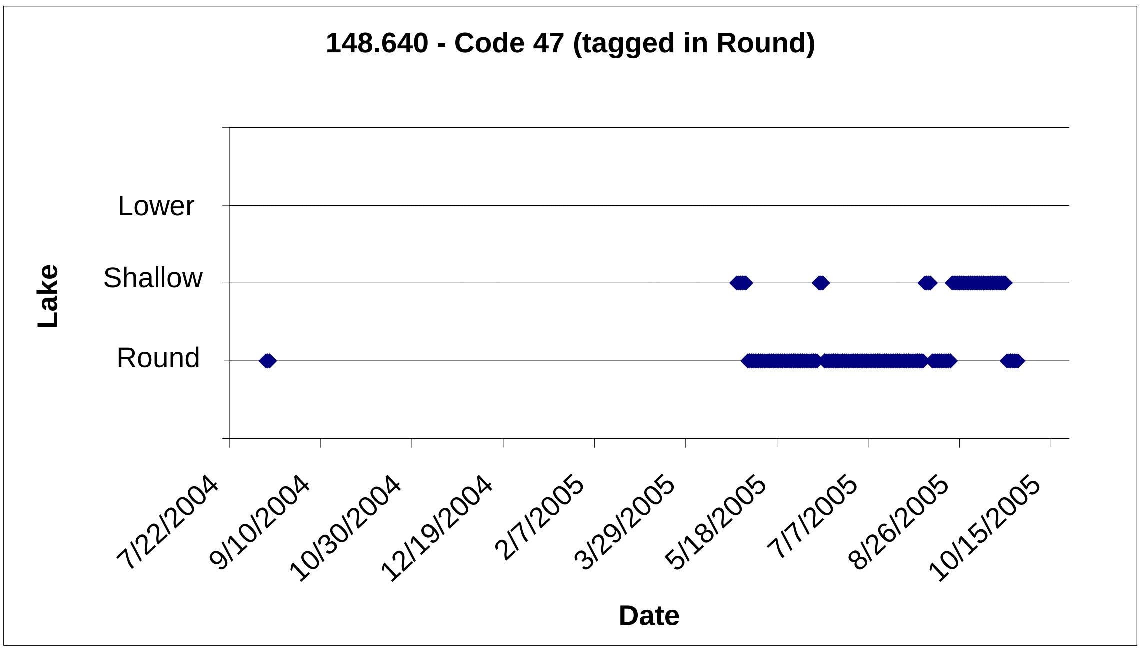
-continued-


148.620 - Code 40 (tagged in Lower)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

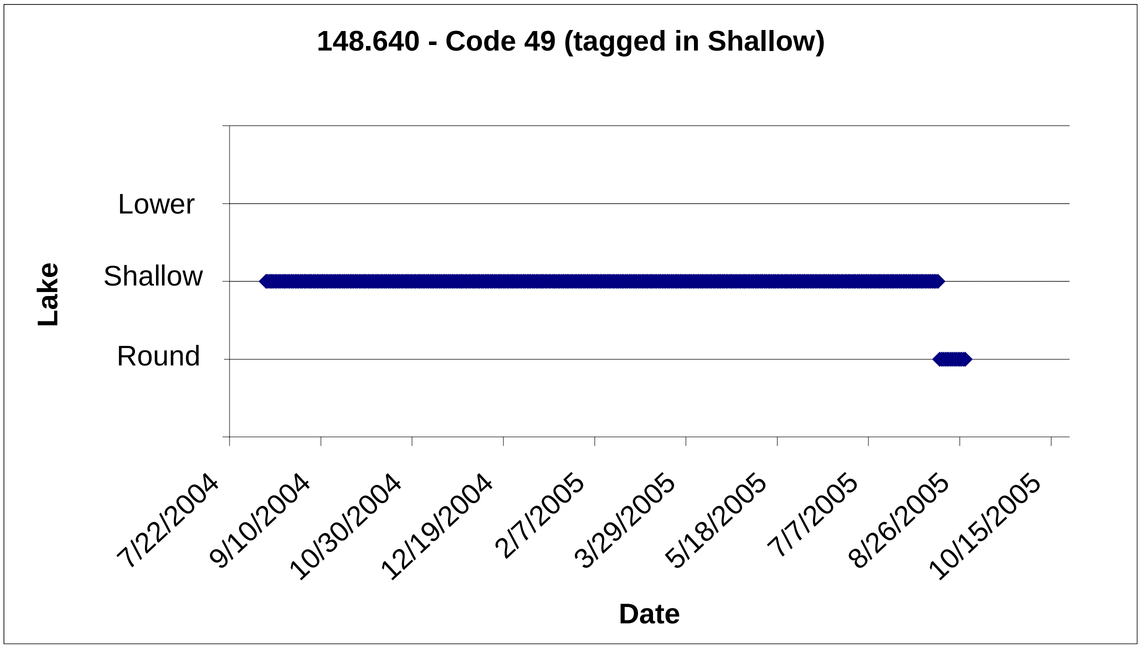

148.640 - Code 44 (tagged in Round)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

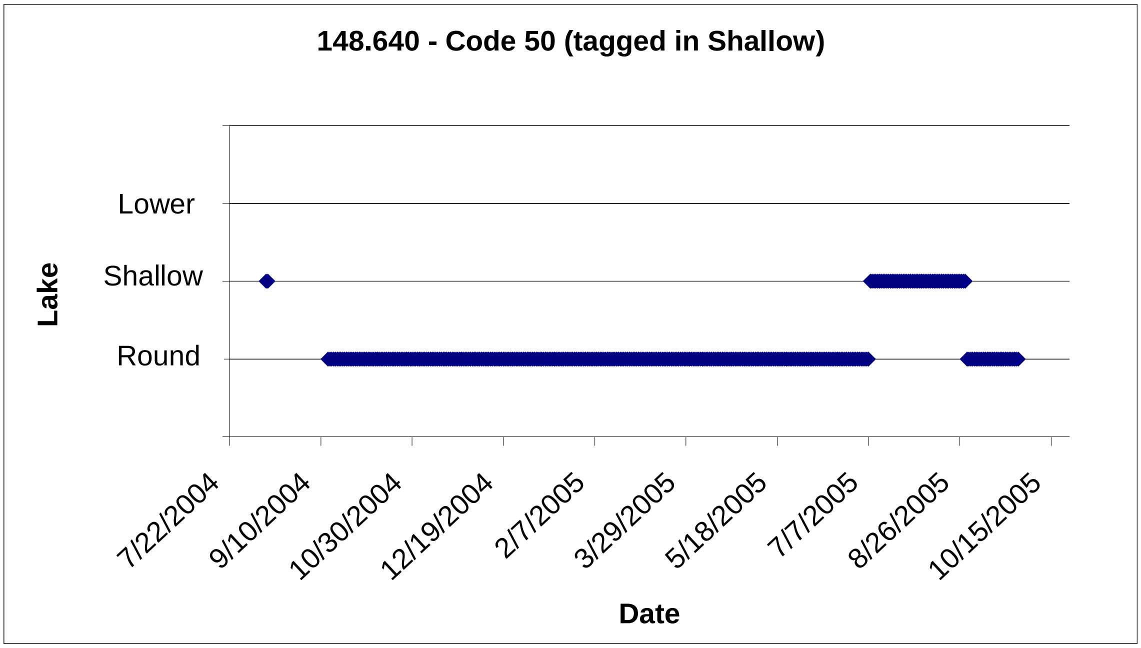
-continued-


148.640 - Code 45 (tagged in Round)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date


148.640 - Code 47 (tagged in Round)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

-continued-


148.640 - Code 49 (tagged in Shallow)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date


148.640 - Code 50 (tagged in Shallow)
Lake
Lower
Shallow
Round
7/22/2004
9/10/2004
10/30/2004
12/19/2004
2/7/2005
3/29/2005
5/18/2005
7/7/2005
8/26/2005
10/15/2005
Date

APPENDIX B
DATA FILE LISTING

Appendix B1-Data files for lake trout captured in the Tangle Lakes, 2004–2005.

Data file	Description
Tangle Lakes LT telemetry analysis.xls	Data and analysis in excel spreadsheet

Note: Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-15